THE

MODERN PRACTICE

OF

BOILER ENGINEERING

BY

ARMSTRONG & BOURNE

92

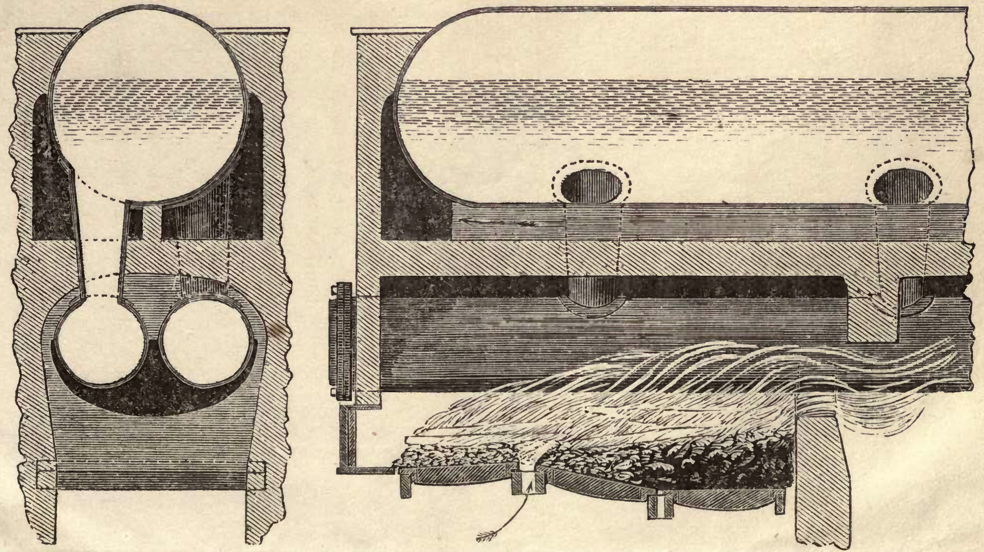
~~gift~~ Steam boiler - A

Horace Davis

Boston. Nov 21. '64.

~~grey~~
off

A NEW CONSTRUCTION OF FURNACE FOR "BURNING ITS OWN SMOKE," AS APPLIED TO AN ELEPHANT BOILER, AND ADAPTED TO THE USE OF WASTE TIMBER, SLACK, AND OTHER MIXED FUEL, BY R. ARMSTRONG, C.E., 1855.



THE

MODERN PRACTICE

OF

BOILER ENGINEERING,

CONTAINING OBSERVATIONS ON THE

CONSTRUCTION OF STEAM BOILERS;

AND UPON FURNACES USED FOR

SMOKE PREVENTION,

WITH A CHAPTER ON EXPLOSIONS.

BY ROBERT ARMSTRONG, C. E.,

CONSULTING ENGINEER.

REVISE D, WITH THE ADDITION OF NOTES, AND AN INTRODUCTION

BY JOHN BOURNE, ESQ.

London:

E. AND F. N. SPON, 16, BUCKLERSBURY.

1856.

CONTENTS.

TO

ROBERT STEPHENSON, Esq., C. E.,

PRESIDENT OF THE INSTITUTION OF CIVIL ENGINEERS,

M.P., F.R.S., &c. &c.

Respected Sir,

I venture to dedicate these pages to you, both as a manifestation of my reverence for the memory of your late Father, of whose genius and persistency I was for many years an admiring spectator; and as a slender token of my sense of your own eminent talents as an engineer, and of your estimable personal character. While some engineering reputations are known to rest on diplomatic adroitness, and others are altogether hollow and conventional, it is known to be your great distinction that the fabric of your fame is as solid as it is imposing, and is held in most esteem by those whose pursuits best enable them to judge of its quality.

I am, dear Sir, faithfully yours,

R. ARMSTRONG.

PREFACE.

THE design of the present work is to place the reader in possession of sound information respecting some of the best kind of boilers at present in use, and also to indicate the course which future improvements to be efficient and of material benefit must necessarily pursue.

The subject of smoke-burning which is reckoned one of the important topics of the present day I have endeavoured to illustrate in such a manner as both to correct the erroneous and exaggerated statements made by interested patentees, and to convey just and moderate ideas upon that subject.

The explosions of boilers is a question still involved in much obscurity, some of which

will I hope be dissipated by the remarks I have offered, and as the general introduction of steam of a higher pressure seems to be inevitable, this is a subject which more than heretofore stands in need of elucidation.

I have much gratification in being able to present the present work enriched by the additions and corrections of Mr. Bourne, which he has kindly furnished in conformity with the friendly feeling which he has constantly manifested towards me for many years.

R. ARMSTRONG.

65, *Fenchurch Street*, *London*,
1856.

INTRODUCTION.

BY JOHN BOURNE, ESQ.

9, BILLITER STREET, FENCHURCH STREET, LONDON.

MR. ARMSTRONG has requested me to revise and add some notes to his present work on steam boilers; a task which my esteem for him has induced me willingly to undertake, though I do not know that any remarks of mine upon this subject can add weight to the doctrines of so established an authority. It is well known to engineers that Mr. Armstrong has had a more extended experience, and possesses probably a more accurate practical acquaintance with boilers and furnaces than any other person now living, and the public has reason to feel grateful that an engineer of such eminent capacity upon these subjects vouchsafes to offer them the fruits of his long and extensive practice. Of all kinds of books there are none so exhausting as books upon practical engineering. Truths of the most eminent value, and results which it may have

required painful labour to collect are despatched in the compass of a few brief sentences, without any manifestation, at least to the cursory reader, of the toil and reflection involved in the brief exposition. Such works are in fact the *essence of thought.* There are consequently few of them written, and it ought to be appreciated as a service to humanity when such men as Mr. Armstrong come forward to lay before the public results which it has taken a life of labour to attain.

The three topics of which Mr. Armstrong has mainly treated in the present work are, first, The Necessity of Strong Boilers; second, Smoke-Burning; and third, Explosions. Upon each of these topics I propose to offer a few remarks, partly in recapitulation of what Mr. Armstrong has said, and partly as exhibiting the results of my own experience, or the nature of my own opinions on those subjects.

HIGH PRESSURE STEAM.

Recent investigations have led to the discovery that heat and power are mutually convertible, and we are able to tell what rise of temperature the expenditure of a given amount of mechanical power would impart to water, and reciprocally what quantity of power a

given quantity of heat if used in a perfect engine would produce. One result of this discovery is the manifestation of the great loss of power in the best existing steam engines. The best class of Cornish engines do not utilize above one tenth part of the heat expended in working them, so that in the best engines about *nine tenths* of the power is lost. The theoretical condition under which we would obtain the full effect of the heat in a steam engine consists in heating the water to the temperature of the furnace, and in suffering this superheated water to expand under such circumstances, that during its expansion it would produce power. In ordinary engines, however, this condition cannot be observed, but it will be approached by using steam of a high pressure and of an elevated temperature. The economy of fuel has now become an object of paramount importance in engines of every class, but more especially so in the case of steam navigation; as there, not merely the expense of the fuel but the expense of carrying it must be incurred. To attain even a moderate measure of economy, steam of a high pressure and elevated temperature is indispensable, and if we have steam of a high pressure we must have a class of boilers introduced into steam vessels which will be

able to bear it. Mr. Armstrong has addressed some of his remarks to this important question, and his opinion seems to be that a modification of that species of boiler termed sometimes the French boiler, and sometimes the Elephant boiler is the most suitable for the altered circumstances of steam navigation. It is clear that a boiler, to be able to bear a high pressure with safety, and without being encumbered with needless stays, should be a boiler with a cylindrical shell, not too large in diameter. The furnace of such a boiler may either be within it or beneath it. I cannot say that I think internal furnaces very safe with high pressures. If they get even slightly out of shape they are liable to collapse; and whereas, in the case of a cylindrical shell, the tendency of the internal pressure is to restore the cylindrical form should it have been accidentally disturbed, in the case of a cylindrical flue or furnace-tube where the pressure is external, the tendency of the pressure is to destroy the cylindrical form, should it have been disturbed accidentally, by overheating or otherwise. My opinion, therefore, is, that a fire beneath the boiler is, so far as regards safety, better than a fire within it, supposing that the water is clean and that there is no deposit. In marine boilers, however, there is a sedi-

ment like mortar, which, if allowed to subside to the bottom of the boiler, and a fire be, at the same time, applied to the bottom, will cause the iron to be burned. But by providing collecting vessels within the boiler the deposit will take place within them, and may be from thence blown out into the sea; and if the operation of blowing off the boilers be sufficiently practised, there will, in point of fact, be no sediment at all. By the application, therefore, of such simple expedients as a collecting vessel and a continuous blow-off, boilers may be employed for marine purposes which will not accumulate scale; and, if the formation of scale be prevented, a species of boiler may be used which will enable high pressure steam to be employed with safety. Steam of this kind, used expansively in the engine, will maintain any required speed of the vessel with a much smaller consumption of coal than would otherwise be required.

In all engines working expansively it is important to maintain the temperature of the cylinder as high as possible, since the temperature of the steam is diminished, and a portion of it is even condensed within the cylinder in consequence of the communication of mechanical power to the piston. For, as a

certain weight of steam has a certain mechanical equivalent which would be realized if the steam could be used in an engine without waste, it follows that the steam, in so far as it exerts power, must lose heat, else it would have both the power and the heat, which is impossible. Accordingly, it is found that there is a larger condensation in the cylinder of an engine which is at work than would take place if the engine were not at work, although the steam is admitted to the cylinder freely in both cases. When the engine is stationary the whole condensation is that caused by the radiation of heat: when the engine is at work we have, besides this cause, the communication of mechanical power to the piston, which can only be effected at the expense of some of the heat, and therefore, with a certain condensation of the steam within the cylinder. In a perfect engine there would be no heat discoverable in the condenser, as the whole would have been changed into mechanical power; and, in all engines, there will be an inferior quantity of heat in the condenser to that which leaves the boiler, by the equivalent in heat of the mechanical power generated in the engine. Steam-jackets act in counteracting the condensation caused by the communication of power.

SMOKE-BURNING.

With respect to smoke-burning, the best species of furnace for the accomplishment of this object, without the introduction of countervailing evils, is one which Mr. Armstrong has designed for Woolwich Dock Yard, on a nearly similar plan to several erected by him in the Arsenal. In this furnace the foremost length of bars slopes somewhat towards the mouth; whereas, the after lengths of bars slope in the contrary direction, or towards the bridge. At the ridge where the opposite slopes meet, there is a double bearing bar which permits some air to enter the furnace in that situation. The coal in the foremost length of bars is maintained in rapid combustion, whereas the coal upon the after tier of bars is undergoing a slow distillation. In charging the furnace, the coal is thrown chiefly to the back end, so that the surface of the fuel slopes forward from the bridge towards the furnace mouth. This coal, being lighted on the top, becomes a kind of coal torch. The gas generated by the heat, in passing through the ignited stratum on the surface, is consumed; and, from time to time, the ignited embers, from which the gas has been expelled, are raked forward, and fresh coal is thrown in to maintain the combustion. Very little smoke is

evolved from this species of furnace; and it differs little from a common furnace, either in construction or efficiency.*

The best species of furnace, however, for marine purposes, is one which, while fulfilling all other indications, will feed the fire by self-acting mechanism. The firing may be accomplished by some of these expedients, not merely in a more efficient manner, but at a materially diminished expense. In the case of a boiler on land, in which a man to look after the engine and boiler is required in any case, the introduction of a firing machine to do a portion of his work is not an object of much importance. But in the case of the furnaces of a steam vessel, which require a number of men to attend upon them every watch, an important economy would be accomplished by the substitution of mechanism of an efficient character.

EXPLOSIONS.

The subject of boiler explosions is still involved

* A representation of this newly designed furnace, as applicable to an "Elephant" Boiler, suitable for dockyards, saw mills, &c., where waste timber and other varieties of mixed fuel are used, is given in the frontispiece.

in a good deal of obscurity. No doubt, a frequent, and, probably, the most frequent, cause of explosion, is the sudden generation of steam produced when the water-level has been allowed to fall so low that the flues get very hot; and then is suddenly raised, so that the water comes into sudden contact with the heated metal. But there are other cases, in which the water is repelled from the iron by a strong heat, though no undue subsidence of the water-level has been suffered to take place. There are boilers in which the natural order of things is reversed when heat is applied,—the water being mostly in the top part of the boiler, and the steam in the bottom. Such boilers necessarily prime very much; or, in other words, much water passes into the steam-pipe, and, at the same time, the part of the boiler on which the flame acts is liable to become overheated from the absence of water in contact with the metal to conduct away the heat. There are boilers in which a lead rivet in the flues may, at any time, be melted out by firing very strongly; the water being so far repelled by the heat as to enable the temperature of the metal to rise to the melting point of lead.

In all boilers in which there is ebullition going on, the apparent level of the water will be greater

than the true level, as the admixture of steam swells the water, producing what is called "false water," by the drivers of locomotives. One effect of this fictitious augmentation of bulk is, that when additional feed water is turned on, from the water level becoming too low, the first effect is still further to lower the water level. This anomaly is caused by the condensation of the steam mixed with the water of the boiler, when an additional quantity of cold or cool water is introduced; but the water level may, at such times, be again raised by easing the safety-valve, which will enable the steam mixed with the water to swell to larger dimensions when the pressure is reduced, and thus compensate for the partial condensation which the introduction of additional feed water has caused.

One cause of boiler explosions Mr. Armstrong considers to be the unskilful application of smoke-burning projects, which, by producing violent alternations of temperature in the boiler bottom, loosen the riveted joints, and, finally, cause them to give way. The occurrence of an accident of this kind in a boiler fitted with the smoke-burning furnace of Mr. Charles Wye Williams has led to a wordy war, which has been waged by that lively gentleman

for many years. Mr. Williams is a species of amateur engineer; who, on the strength of an acquaintance with the atomic theory, and other elementary chemical truths, acquired, apparently, late in life, has set up as the engineering reformer of the age, in the department of smoke-burning; and he has obtained the approbation of the "Mechanic's Magazine" and other oracles of corresponding authority. A man's ambition need not be very exalted, which is satisfied with such successes; but if there be gratification sufficient to compensate the ridicule arising from harping eternally upon a single trumpery topic, there is no reason, that I know of, why it should not be possessed.

The subject of locomotive boilers has been treated more fully by Mr. D. K. Clark, in his excellent work on "Railway machinery," than by any other author, and he has shown that it is inadvisable to make the area of fire-grate or the area of the chimney very large, that the smoke box should not be of greater capacity than is absolutely necessary to collect the hot air from the tubes, and that the blast-pipe should stop short, by a few inches, of the foot of the chimney, instead of penetrating into it. The following table is taken from Mr. Clark's work :—

TABLE OF THE PROPERTIES OF SATURATED STEAM; FROM REGNAULT'S EXPERIMENTS.

Total pressure per square inch.	Relative volume.	Temperature.	Total Heat.	Weight of one cubic foot.
lbs.		Fahr.	Fahr.	lbs.
15	1669	213·1	1178·9	·0373
16	1572	216·3	1179 9	·0397
17	1487	219·5	1180·9	·0419
18	1410	222·5	1181·8	·0442
19	1342	225·4	1182·7	·0465
20	1280	228·0	1183·5	·0487
21	1224	230 6	1184·3	·0510
22	1172	233·1	1185·0	·0532
23	1125	235·5	1185·7	·0554
24	1082	237·9	1186·5	·0576
25	1042	240·2	1187·2	·0598
26	1005	242·3	1187·9	·0620
27	971	244·4	1188·5	·0642
28	939	246·4	1189·1	·0664
29	909	248·4	1189·7	·0686
30	881	250·4	1190·3	·0707
31	855	252·2	1190·8	·0729
32	830	254·1	1191·4	·0751
33	807	255·9	1192·0	·0772
34	785	257·6	1192·5	·0794
35	765	259·3	1193·0	·0815
36	745	260·9	1193·5	·0837
37	727	262·6	1194·0	·0858
38	709	264·2	1194·5	·0879
39	693	265·8	1195·0	·0900
40	677	267·3	1195·4	·0921
41	661	268·7	1195·9	·0942
42	647	270·2	1196·3	·0963
43	634	271·6	1196·8	·0983
44	621	273·0	1197·2	·1004
45	608	274·4	1197·6	·1025

(Continued.)

Total pressure per square inch	Relative volume.	Temperature.	Total Heat.	Weight of one cubic foot.
lbs.		Fahr.	Fahr.	lbs
46	595	275·8	1198·0	·1046
47	584	277·1	1198·4	·1067
48	573	278·4	1198·8	·1087
49	562	279·7	1199·2	·1108
50	552	281·0	1199·6	·1129
51	542	282·3	1200·0	·1150
52	532	283·5	1200·4	·1171
53	523	284·7	1200·8	·1192
54	514	285·9	1201·1	·1212
55	506	287·1	1201·5	·1232
56	498	288·2	1201·8	·1252
57	490	289·3	1202·2	·1272
58	482	290·4	1202·5	·1292
59	474	291·6	1202·9	·1314
60	467	292·7	1203·2	·1335
61	460	293·8	1203·6	·1356
62	453	294·8	1203·9	·1376
63	447	295·9	1204·2	·1396
64	440	296·9	1204·5	·1416
65	434	298·0	1204·8	·1436
66	428	299 0	1205·1	·1456
67	422	300·0	1205·4	·1477
68	417	300·9	1205·7	·1497
69	411	301·9	1206·0	·1516
70	406	302·9	1206·3	·1535
71	401	303·9	1206·6	·1555
72	396	304·8	1206·9	·1574
73	391	305·7	1207·2	·1595
74	386	306 6	1207·5	·1616
75	381	307·5	1207·8	·1636
76	377	308·4	1208·0	·1656
77	372	309·3	1208·3	·1675
78	368	310·2	1208·6	·1696
79	364	311·1	1208·9	·1716
80	359	312·0	1209·1	·1736

TABLE OF THE PROPERTIES OF SATURATED STEAM; FROM REGNAULT'S EXPERIMENTS.

(Continued.)

Total pressure per square inch.	Relative volume.	Temperature.	Total Heat.	Weight of one cubic foot.
lbs.		Fahr.	Fahr.	lbs.
81	355	312·8	1209·4	·1756
82	351	313·6	1209·7	·1776
83	348	314·5	1209·9	·1795
84	344	315·3	1210·1	·1814
85	340	316·1	1210·4	·1833
86	337	316·9	1210·7	·1852
87	333	317·8	1210·9	·1871
88	330	318·6	1211·1	·1891
89	326	319·4	1211·4	·1910
90	323	320·2	1211·6	·1929
91	320	321·0	1211·8	·1950
92	317	321·7	1212 0	·1970
93	313	322·5	1212·3	·1990
94	310	323·3	1212·5	·2010
95	307	324·1	1212·8	·2030
96	305	324·8	1213·0	·2050
97	302	325·6	1213·3	·2070
98	299	326·3	1213·5	·2089
99	296	327·1	1213·7	·2108
100	293	327·8	1213 9	·2127
101	290	328·5	1214·2	·2149
102	288	329·1	1214·4	·2167
103	285	329 9	1214·6	·2184
104	283	330·6	1214·8	·2201
105	281	331·3	1215·0	·2218
106	278	331·9	1215·2	·2230
107	276	332·6	1215·4	·2258
108	273	333·3	1215·6	·2278
109	271	334·0	1215·8	·2298
110	269	334·6	1216·0	·2317
111	267	335·3	1216·2	·2334

(Continued.)

Total pressure per square inch.	Relative volume.	Temperature.	Total Heat.	Weight of one cubic foot.
lbs.		Fahr.	Fahr.	lbs.
112	265	336·0	1216·4	·2351
113	263	336·7	1216·6	·2370
114	261	337·4	1216·8	·2388
115	259	338·0	1217·0	·2406
116	257	338·6	1217·2	·2426
117	255	339·3	1217·4	·2446
118	253	339·9	1217·6	·2465
119	251	340·5	1217·8	·2484
120	249	341·1	1218·0	·2503
121	247	341·8	1218·2	·2524
122	245	342·4	1218·4	·2545
123	243	343·0	1218·6	·2566
124	241	343·6	1218·7	·2587
125	239	344·2	1218·9	·2608
126	238	344·8	1219·1	·2626
127	236	345·4	1219·3	·2644
128	234	346·0	1219·4	·2662
129	232	346·6	1219·6	·2680
130	231	347·2	1219·8	·2698
132	228	348·3	1220·2	·2735
134	225	349·5	1220·6	·2771
136	222	350·6	1220·9	·2807
138	219	351·8	1221·2	·2846
140	216	352·9	1221·5	·2885
142	213	354·0	1221·9	·2922
144	210	355·0	1222·2	·2959
146	208	356·1	1222·5	·2996
148	205	357·2	1222·9	·3033
150	203	358·3	1223·2	·3070
160	191	363·4	1224·8	·3263
170	181	368·2	1225·1	·3443
180	172	372·9	1227·7	·3623
190	164	377·5	1229·1	·3800
200	157	381·7	1230·3	·3970

With these cursory remarks I dismiss Mr. Armstrong's present work. Its main suggestions, namely, the necessity of the adoption of cylindrical boilers in all cases in which economy of fuel is important, the practicability of burning smoke by simple arrangements without, however, the accomplishment of much, if any direct saving of fuel, the advantage of fire feeding mechanisms in steam vessels, and the doctrine of the accidental deficiency of water in boilers being the main cause of explosions, are all, in my judgment, sound doctrines, and, if so, public benefit cannot fail to arise from their wide acceptation.

J. B.

NOTE TO REGNAULT'S TABLE, PREVIOUS PAGE.

The above table of corresponding pressures, temperatures, and volumes of saturated steam is by the kind permission of Mr. Clark copied from his valuable work. The pressures and temperatures are the direct results of M. Regnault's experiments. The relative volumes are obtained by means of the formula

$$v = 37 \cdot 3 \, \frac{458 + t}{p}.$$

The fourth column is the result of direct experiment by Regnault. And the fifth column is calculated by dividing 62·321 lb., the weight of a cubic foot of water at 62° by the relative volume.

CHAPTER I.

ON BOILERS GENERALLY, AND A RADICAL REFORM IN THOSE FOR MARINE PURPOSES SUGGESTED.

THE main design of this short essay is to impart in few words, that information respecting boilers and furnaces, which persons employing steam-engines, desire to possess, but which they have not much time to acquire. While yielding our approbation to all investigations touching the science of steam, which seem likely to illustrate its nature, we are at the same time conscious that the bulk of mankind immersed in active business, have but little time for such speculations; and it is our design rather to state results, and enunciate general laws, such as are found to govern successful practice, than to embark upon the wide sea of theoretical disquisition, or to announce any mere theoretical conclusions. Still less is it our intention to parade the elementary truths of chemistry as baits for the admiration of the ignorant—expanded into all the forms proper to laborious dul-

ness and varied in every phrase of emphatic iteration. *That* task has already been performed by Mr. Charles Wye Williams in his work on the "Combustion of Coal and the Prevention of Smoke," and the merits in which that work is deficient have been compensated by its artificial notoriety. We should be sorry to deprive Mr. Williams of any portion of the reputation which has cost him so much and the quality of which seems to satisfy his ambition, and there is certainly no danger that in the present work we shall run into any similar extravagance, having so painful an example before us of this species of folly. To theory we take no exception, theory being indeed only the connection of individual facts into such a chain as to constitute a natural law.

HAY-STACK BOILER.

This boiler is termed the hay-stack boiler from its shape. In some districts it is called the *balloon boiler*, and the *kettle boiler*. It is a good kind of boiler up to 10 or 12-horse power, and 10 or 12 lbs. pressure, where boilers are required to stand singly. It is strong enough within those limits, and has the greatest capacity for the least quantity of material

employed. Independent of its economy, which, with inferior fuel, need not be less than that of any other kind, it has, perhaps, the greatest evaporating power for its dimensions, and if set up, as it usually is, with a single wheel draft, it requires only a small chimney. The shape of the bottom of this boiler is generally not so well adapted as some other kinds of boilers for applying the usual arrangements for consuming smoke, but if made of copper, as such boilers are in some of the London breweries, they admit of coke being used to very great advantage.

In Staffordshire, and some other mining districts, the hay-stack boiler has been frequently made much too large; and where this defect has been sought to be corrected, by carrying the flue spirally twice round the boiler, the result has usually been unsuccessful, if not dangerous.

THE WAGGON BOILER.

This boiler is, in principle, the hay-stack boiler just described, only put into an *oblong* instead of a circular form on the ground plan. It therefore permits of facilities in arranging a number of boilers side by side without wasting space. It is distin-

guished in mining districts as the *oblong* boiler. In other places it is sometimes called the *caravan* boiler, and by Mr. Wicksteed, the *waggon-head* boiler. It possesses some advantage over the hay-stack boiler in its being better adapted for the use of rich bituminous or flaming fuel, and Newcastle coal generally. It admits of being made of such a length, that the flame from a well-managed fire will be generally expended before reaching the end; and it can be easily varied in its proportions to suit the many varieties of flaming fuel—wood as well as coal. As flaming coal is also *smoky* coal, the waggon boiler from its rectangular plan, is suitable for the application of such coal, because it admits of the ordinary rectangular fire-grate, with convenient space beyond for any arrangement of the furnace chamber and bridges, so as to meet almost any requirement for smoke-consuming purposes.

The waggon boiler is, except in the direction of its length, nearly as strong as the hay-stack boiler, up to 5 feet diameter, and if provided with one, two, or three longitudinal stays, and 4 such stays of $1\frac{1}{2}$ inch square from end to end if above that diameter, together with cross stays at every two feet in the length, it may be safely worked up to 10 lb. on the

square inch. For this pressure it is usually made of plates to average $\frac{3}{8}$ inch thick all round, the top being never less than $\frac{1}{4}$, and the ends ought to be seven-sixteenths of an inch. Up to 20 or 25 horse-power, boilers which are as many feet in length by 5 to $5\frac{1}{2}$ feet wide, or equivalent proportions, made in this way, will weigh 17 or 18 lb. per square foot of total surface, inclusive of rivets, overlap of plates, stays, &c. 17 or 18 square feet of such surface, may be reckoned as equivalent to a horse-power; from these data, the weight and cost (at present 25 to 30 shillings per cwt.) is soon obtained.

Within the above limits, no boiler ever made can exceed this one in efficiency, economy, and durability, if well-proportioned to the engine it works, and to the fuel supplied to it. If required of greater power than 20 or 25 horse, boilers of this kind are made deeper in proportion to their length, and an internal *flue tube* is introduced, and such boilers are then called the

BOULTON AND WATT BOILER.

This boiler, when of 30 or 40 horse-power, is more economical in fuel than the plain waggon form; but is weaker for the same thickness of iron, and ought

not to be worked at more than 8 lb. per square inch. Its power is calculated in the same way as that of the waggon boiler, excepting only that the breadth or diameter of the internal tube is to be considered as so much added to the width of the boiler itself. Thus, if a waggon boiler of 20 feet long, by 5 feet wide, be equal to 20-horse power, being at the usual rate of 5 square feet of water surface, or horizontal ground plan per horse power,—then a Boulton and Watt Boiler of the same horizontal dimensions externally, but having its inside flue tube of 2 feet diameter, will be *two-fifths* more powerful, or 28 instead of 20-horse power, it must be supplied, of course, with a proportionate increase of fire-grate, and is thus computed:—

$$\begin{array}{l} \text{Length} \\ \text{Divided by} \end{array} \frac{20 \text{ ft.} \times (5 + 2 =)\ 7 \text{ ft. wide}}{5 \text{ feet per H.P.}} = \frac{140}{5} = 28$$

horse power.

With these dimensions, however, it would have to be of very considerable depth, in order to have the required capacity for holding a sufficient quantity of water and steam for that power. It is therefore found preferable to make such boilers from 6 to 8 feet wide, by 8 or 9 feet deep, and they should never be more than 28 or 30 feet long. If a boiler of this

kind is not required to be above 40 horse power, there is no necessity, unless very bituminous coal is used, for its being much more than 20 feet in length. With that length it may be made 6 ft. 6″ wide, by 8 ft. or 8 ft. 6″ deep, and contain a circular flue-tube of $3\frac{1}{2}$ ft. diameter. The computation in the same manner as above, will then stand as follows:—

$$\frac{20\text{ ft.} \times (6\text{ ft. }6'' + 3\text{ ft. }6'' =)\ 10\text{ ft.}}{5} = \frac{200}{5} = 40\text{ H.P.}$$

As in my former works upon steam boilers, I gave some examples of the arithmetical calculations connected with this subject, at full length, for the special benefit of engine-men and stokers; and having since ascertained the utility of such numerical examples for the purpose intended, I shall give a similar example here:—

Width or diam. of boiler		6·5 feet.
Ditto of inside flue-tube		3·5
		10·0
Multiply by the length		20
Divide by	5	200
		40-horse power.

The slide rule formula for all such cases is,

A	Gauge point 5	or 5·7	diam. of boiler and flue 10
Ↄ	Horse power 40	35	Length of ditto 20

If the second divisor or gauge point 5·7 be used, which gives about a square yard, or 9 square feet of effective heating surface per H. P., the result is seen to be only 35 H. P. But, by placing 40, the power required, opposite to 5·7 in the place of 35, we shall find, opposite to 10, the proper length to make the boiler 40-horse power at that rate, namely 22·8 feet as below,

A	5·7	diameter 10	or $11\frac{1}{2}$
Ↄ	40	length 22·8	20

or, retaining the same length 20 feet as before, opposite to it is seen $11\frac{1}{2}$ as above, for the diameters of boiler and flue together, which may be conveniently made 8 feet, and 3 feet 6 inches respectively.

A Boulton and Watt Boiler, thus proportioned, is much more economical of fuel than a waggon boiler of the same size or power; but it requires more total surface of iron plate, although it is measured precisely in the same way, that is, the *lower half* of all the flues is left out in the measurement, as non-effective in generating steam, and one half only of the vertical

heating surface is considered as *effective* heating surface.

In respect to strength, this boiler is weaker than the unflued waggon form, in proportion as its depth exceeds its diameter; notwithstanding it may be made of thicker plates in proportion to its increased size. This defect is partially remedied by having *two* tiers of cross stays $1\frac{1}{2}''$ square, placed one above, and the other below the inside flue. Besides these cross stays, it is usual to support the bottom of the boiler by oblique stays, commonly called "upright" stays, attached to the arch of the boiler bottom, and the other end secured by cotters upon, and near the ends of the upper cross stays. All these stays of which there are 4 for each plate in the length of the boiler, are attached by broad wrought iron straps and cotters, which last should not be made too taper, for when so, they are liable to wriggle loose by the working of the boiler. Besides the usual number of longitudinal stays from end to end, as in the plain waggon boiler, some persons put in "angle stays," extending from near the centre of each end, to the second or third plate on each side. Again, we occasionally find a stay carried obliquely downwards from the flat end of the boiler to the top of the flue tube, which we consider injudicious,

and rather tending to do harm than good. For the tube itself generally is, or should act as a stay from end to end; and on that account should not be drawn out of its direct tensile action by any side attachment, liable to create lateral strain. The probable reason why stays were originally placed in this part by Boulton, Watt and Co., is that they did not latterly carry the flue-tube right through from end to end, but terminated it in a *flat* topped "take up" inside the boiler, to support the top plate of which this oblique stay assisted. With respect to similar oblique or angular stays carried from the ends to the *arched top* of the boiler, we cannot say much in their favour, although some of them have become popular under the name of "*gusset*" stays, from their being made of triangular plates instead of square bars, which would, we think, be more suitable, if needed at all. However appropriate these gusset stays, or stay *plates*, instead of stay *bars*, may be in plate iron bridges and structures of that kind, where stiffness from external pressure and from twisting is the main object in view, any peculiar value they can have in resisting the internal strains to which steam boilers are subject, is not very apparent, especially when we consider that every unnecessary rivet, not to say seam of rivets, in a boiler is a source of weakness, not strength.

If larger boiler plates could be manufactured, or could large plates be as easily ascertained to be sound as small ones, then the less rivetting the better. Since the new system of welding, instead of rivetting the edges of boiler plates together has been so far perfected by the patent process of Mr. Bertram, late of Woolwich Dockyard, as to prove its superior strength to even double rivetting, it is not now too much to look forward to the time when not only a boiler, but the iron hull of "the noblest machine that ever was invented" a SHIP, instead of being, as it may now be termed, "*stitched*" together in patches by "seams" and "gussets," will be *forged* in one entire piece; at all events, Mr. Bertram has demonstrated the practicability of welding together iron plates in a cheap, rapid, and efficient manner, and there can be no doubt that his discovery must in time find many valuable applications.

MARINE BOILERS.

In this country marine boilers are almost all low pressure boilers, but the pressure has been gradually creeping up for several years, and pressures of from 20 to 30 lbs. on the square inch, are now by no means unusual. At the same time no corresponding

improvements have been made in the structure of the boilers to ensure an equal measure of safety to that which previously existed. No doubt modern marine boilers are made of good iron, are well rivetted and are very much stayed. But the stays, especially in the region of the steam chest, are speedily corroded by the action of the steam; the plates of the boiler also get thin, so that unless the engineer reduces the weights on the safety valve as the boiler gets worn, explosion will be apt to occur from mere weakness of the boiler.

For tug boats and other commercial purposes, for war, and for sea-going vessels generally, we do not see how very high pressure, whether with condensing or non-condensing engines, and for war ships, *extreme* high pressure is to be avoided. The economy of the combined high and low pressure engine, and the advantages of working very expansively, in various ways are so great, and so much more important *afloat* where the fuel has to be *carried,* than ashore, that it has long been a problem, whether it would not eventually be true economy to adopt the very strongest boilers which can possibly be made at once. Say to be able to work at not less than 100, and up to 200 lb. on the square inch; and we really see no very great

difficulty in making boilers quite as safe from explosion at 200 lb. as the ordinary marine boilers as now made, are at 20 lb. pressure. It is merely a question of investment of capital, not in *large* ships, but in *strong* ships, so that we are inclined to side with those who would adopt such a system as good commercial policy. Because if the boilers are capable of working safely at 200 lbs. there is no reason why, with proper arrangements, such boilers with suitable engines, should be less economical than ordinary boilers if worked at ordinary pressures. The greater cost of the boiler in the first instance will not only confer greater strength but greater durability.

The present construction of the *multitubular* boiler, as it is called, may be truly stated as a disgrace to the science of this age of progress. The marine boiler yet remains, in fact, no more than a locomotive boiler, with the most important part of that boiler, the fire-box left out. It is not that we would put a fire-box, or anything like it, aboard a steam ship, though well adapted to the rail; that is only suited for burning coke which is too bulky a fuel for marine purposes. Besides a blast or strong draft by some means seems a necessity for burning coke with advantage.

Very much more, however, is either the blast or jet required, by reason of the multitude of small tubes through which the products of the combustion must be drawn. This creates an additional difficulty with the present marine boiler, and it is not likely that from 20 or 30 per cent. of its power can be afforded for blowing the fire, as is the case with some locomotives.

What then, it may be asked, is the first step to improve the present practice? And my answer is ready, If a *moderate* improvement only is permitted, without greatly disturbing present arrangements of space in the ship, and a due regard to venerated prejudices, which we have seen created during a single generation, and which have in that time erected the crude suggestion of Booth, successful though it has been made by others, almost into the position of an institution, the obvious course is to *improve the furnaces, shorten and widen the tubes,* and, when draft is deficient, *apply the exhausting fan* with a short funnel. Although we do not insist so strongly on the last item, it may be observed in passing, that it would make "smoke burning" *with economy* in steam ships possible; at present it is not. (*See* Chap. ii.)

Should a radical reform of the marine boiler be aimed at,—and we have never ceased strenuously to

urge its necessity,—whoever attempts it must not stick at trifles. The boilers, in the first place, ought not to be "crushed down" to the bottom of the ship, where the draft has such difficulty to descend down after them. We would, in fact, abolish the stoke-*hole,* if not do away with the stokers, and *stoking* also. Instead of placing the fires so low down that, in a leaky ship they are soon drowned out, we would have them close up to the deck, in whatever situation the engines might be fixed. The "firing stage" should really be a platform elevated to the light of day, on which the most important processes in the economy and progress of a steam vessel is carried on, and to which the coals may be elevated, and, if required placed in the furnaces also, by means of very simple self-acting mechanical appliances. In giving a reluctant assent to the proposition, let it not be forgotten by the reader, that this change of position in the boilers would really *increase* the available room for cargo, inasmuch as none would be wasted in passages up and down for the hands, and for ventilation, to say nothing of the greater safety of the ship from *fire;* and though last, not least, when we think of the possible fate of the "President" or the "Pacific," from *explosion.*

In the case of vessels of war where the boilers, in this elevated position, might be obnoxious to the effects of shot, &c., the boilers may be retained in the usual position, and in such cases the room occupied by the stoking space is not so objectionable. Wrought iron boilers of simple forms, containing a steam pressure of 200 lbs. per square inch, will be the most suitable in such cases.

The communication of the boilers with each other, and with the cylinders may be easily arranged below the water level in the manner of the locomotive.

The kind of boilers we propose for marine purposes, are not new schemes, but the inventions of practical men, matured by the experience afforded by extensive use. The principle is that of Woolf where the pressure is exerted only *within* cylinders of comparatively small diameter, say up to 2½ or even 3 feet. The species of boiler made by Hall of Dartford, and others, known in London as the *elephant* boiler, may be arranged to work at a pressure of 150 to 200 lbs., and for low-pressure (say 80 to 100 lbs.) when used in wooden vessels where *internal* furnaces are insisted on, we would recommend the modification patented by Galloway, of Manchester. The elephant boiler has been much used by the French, though but par-

tially, perhaps, for steam navigation. Galloway's boiler has been used in this capacity, I believe, to some extent; my own immediate experience with both has been principally confined to *land*. The latter boiler was first introduced into practice in London, and erected for public inspection and trial at the Great Exhibition in 1851. This boiler I shall now describe.

THE GALLOWAY CONICAL TUBE BOILER.

I use the term "conical," rather than "patent," in the designation of this boiler, because the patentees have other patent boilers, also with vertical tubes, which tubes are not all conical, being partly "fire tubes" or, strictly speaking, small tubular flues, on the principle of the locomotive; and also to distinguish it in its most prominent feature, in relation to strength and durability, from the boilers of the American steamers "Pacific" and "Baltic," Collins's line. The great and most important point of difference between the American and English boiler is, that in the former, the large internal fire-flue, or flame-chamber is occupied by a great number of *parallel* tubes, about 2 inches diameter, and 5 feet long, placed vertically, and connecting the upper and lower portions of the water chamber. Through these

tubes the water, of course, circulates very rapidly, and there can be no doubt this arrangement forms a most effectual means of warming a large quantity of water in a short time, and with great economy. Whereas in the Galloway boiler, the space behind the furnace is occupied by a smaller number of *taper*, or conical tubes of 5 or 6 inches in diameter at the lower, and nearly double that diameter at their upper ends; consequently requiring more space in length of boiler, though less in depth, than the American plan, for the same quantity of heating surface.

In a pamphlet written by Captain Ramsay, R.N., published in 1851, entitled, "Remarks on some of the causes that retard the progress of our STEAM NAVY," several good observations are made in illustration of the necessity of using much higher steam than previously, in ships of war, and the difficulty in attaining that object with the ordinary construction of marine boiler, as well as on the ill-adaptation of that boiler with small tubes to the proper combustion of bituminous coal or other flaming fuel. In discussing this subject, Page 58, Captain Ramsay remarks,—

"The strongest form of boiler which we are acquainted with is one invented by Messrs. J. and W.

Galloway of Manchester, and which, we believe, might, with modifications, be adapted to marine purposes. The peculiar principle of this boiler is the series of short vertical tubes which act as stays. The only objection to which these boilers are liable, as marine boilers, would be, that using *water* tubes, there is a liability to prime; but we would meet that objection by making the upper part of the tubes very large in proportion to the lower parts."

Now this last suggestion is a very important one, and had been previously made by the present writer, not with a view to prevent priming, solely, but also for insuring a more effective action of the flame against the sides of the tubes, as well as to prevent their being injured by overheating and burning out at their upper ends. In fact, I professionally advised the inventors, on being consulted by them, previously to taking out their patent for this water-tube boiler, in 1850, to adopt that course. This advice they followed, and have continued to pursue, with very great success ever since. Messrs. Galloway having supplied several 50 horse boilers, for the Gutta Percha Company's Works, City Road, and to several other factories in London, during that and the following year.

One of those boilers, erected under my superintendence, at the City Road Works is described and figured in my "Rudimentary Treatise on Steam Boilers." In that work it was stated that this boiler was capable of evaporating a cubic foot of water per minute, with only about 6 lbs. of bituminous coal per hour, not of the best quality, while driving a 30-horse non-condensing engine indicating 50-H.P., besides supplying steam for other purposes. This great, if not unprecedented, degree of economy has been doubted by some persons who have in vain tried to evaporate a cubic foot of water by less than 8 or 9 lbs. under the same circumstances: that is, *while driving an engine at full work,* which is a very different thing to the kind of evaporating experiments some time ago carried on by order of Government, and published in sundry Reports to Parliament on coals suited to the steam navy. These Reports are merely an account of the results of certain laboratory experiments, and, however valuable as scientific facts such investigations may be, it must be said that the labours of the eminent men engaged have been of little use in improving or illustrating the actual practice of engineers. The highest result obtained in these experiments was, 10·21 lbs. of

water evaporated from 212° for each lb. of the best Welsh coal. (Ebbw Vale.) This result was obtained with a Cornish boiler. With a Galloway boiler, however, when new, with thinner tubes, that is, ¼ inch instead of five-sixteenths, and welded up the side instead of being rivetted, I have, occasionally, obtained a larger performance than that given in the statement referred to. The result of the experiment in question was, that eleven and one-tenth pounds of water was evaporated by each lb. of coal consumed of an inferior kind called *East Adair's main.* The pressure of the steam was carefully kept up during the experiment, (nearly 2 hours,) at exactly 40 lbs. per square inch, the engine doing its ordinary work, except that the feed pump was stopped off, and, consequently, no feed-water was going into the boiler, which enabled me to measure very accurately the fall of the water-level in the glass water-gauge; and, knowing the exact internal dimensions of the boiler, the quantity of water boiled away was thus clearly ascertained with sufficient exactness for a short experiment: at any rate, the result was as near the truth as the quantity of coal used could be measured, considering that the quantity of fuel on the bars had to be *estimated,* to be equal at the beginning and the end of

the experiment. At that time (1850) no such thing as an absolutely correct water-meter, at a moderate expense, for *boilers,* was in existence; that desideratum, however, now appears to be attained by the invention of Mr. Kennedy of Kilmarnock. So important an appendage to steam boilers as a correct *boiler-meter,* constantly registering the quantity of water boiled away, has been long looked for and longed for by every honest engineer. Besides being a continual check against that neglect of the feed-water which too frequently results in explosions, it will also be a serviceable check on the extravagant expectations often raised upon the statements of interested patentees of their schemes for saving fuel. I do not risk much in predicting that when these meters become more generally known and used, they will produce a revolution in the engine and boiler trade, quite as great as was produced by the first general introduction and improvement of Watt's indicator, by the late Mr. John M'Naught of Glasgow; an era which makes us now look back to those times of hemp-packed pistons, "never tight," and air-pump buckets "never meant to draw," as to a long-bygone age, though but few years have elapsed since that barbarous time. And now, by the help of

the *boiler-meter,* we hope soon to dispel the present uncertainties of some hundreds of smoke patentees as to whether their plans save seven per cent. of fuel, or *seventy,* although, for aught they know, they are just as likely to do one as the other; but I have a strong suspicion that the best of them,—and I am far from denying that there are many good ones,—will be found to come nearer *two* per cent. than twenty.*

* Except, perhaps, 20 per cent. *below par, negative* "saving." But we trust this subject will yet receive, as it deserves, more serious treatment. At a meeting of smoke patentees, called by the authorities of Leeds, some years ago, one, the most notorious of them, whom we will call No. 1, promised 50 per cent. saving in fuel. No. 2, equally well known, promised 60! while others promised 70 and 80!! not being particular to a few per cents., whom we may call, collectively, No. 3. The results are,—No. 1 sent a new steam ship to sea with his plan, which ship very narrowly escaped the fate of "the President," being, only through the greatest care and discretion of her commander, brought back to Cork, to repair her boilers, *after being nine days out on her way to America.* No. 2 had his plan in operation not far from the Manchester Exchange, which ended in a well-known terrible explosion, killing nine or ten people. While No. 3, an 80 per cent. man, has more recently had one of the most destructive explosions on record in Yorkshire.

Reverting to our evaporating experiment at the Gutta Percha Works; the pressure being 40 lbs., the temperature of the steam and, of course, the water also, was at about 288° Fahr. In order to compare with the ordinary practice, the evaporation of 11·1 to 1 must be reduced to what it would be were the boiler supplied at the ordinary standard temperature of 100°, which, by the Admiralty rule for that purpose, assuming the latent heat of water at 1000° is as follows :—

$$\frac{(1212° - \text{actual temp. } 288°) \times 11{\cdot}1}{(1212 - \text{standard temp. } 100) = 1112} = 9{\cdot}2 \text{ lbs.}$$

water to one of coal.

It is proper to state that the rate of combustion did not much exceed 10 lbs. of coal per square foot of grate bar per hour, and that the experiments were repeated in the presence of several competent witnesses, occasionally reaching a corrected evaporation of $10\frac{1}{4}$ lbs. of water to 1 lb. of coal; or, in other words, a Galloway boiler made a common variety of bituminous Newcastle coal, in ordinary practice, go as far as the *best Welch* in a pet experiment with the far-famed Cornish boiler.]

In order to arrive at the best proportions to be

observed in a boiler of this kind, we have ample experience to rely upon. Besides the experience afforded by the great number made by Messrs. Galloway, both for land and steamboat purposes during the last three or four years—there is a sufficient number of them in the metropolis for the purpose of illustration. The dimensions of the boiler at the Gutta Percha Works, above referred to, where the evaporation experiments were made, are as follows:—

Length of boiler 30 feet 3 inches. Diameter of ditto inside, seven feet. Greatest diameter of main flue, 4 feet 6 inches inside, by 3 feet deep, containing 13 conical water tubes, each 11 inches inside diameter at top, and 9 inches at bottom, which tubes act as prop stays between the flat top and bottom of this main flue. The entrance to this main flue is by two parallel and similar furnace tubes, each 8 feet long, and somewhat *oval* in section, being 2 feet 6 inches wide, by 2 feet 9 inches deep. But they are stronger than if they were circular, on account of containing three strong cast iron bearing bars for supporting the grate, which act as prop stays from side to side. The fire-grates are each 7 feet 4 inches long, by 2 feet 6 inches wide, containing about $\frac{3}{4}$ square foot of fire bar area per horse power for the

50-horse boiler. Each of the furnaces contained two lengths of fire-bars, the front bars being 1 inch, and those at the back $1\frac{1}{4}$ thick with $\frac{3}{8}$-inch spaces between them in both cases. This pitch of the bars was adopted without my concurrence, otherwise I should have preferred the front bars $\frac{1}{2}$-inch thick, with the same spaces, and the back bars with $\frac{1}{4}$ or five-sixteenth spaces, instead of $\frac{3}{8}$, in order to attain a more perfect combustion of the smoke; that being the object for which Messrs. Galloway originally adopted the double furnace plan. These grates have since been replaced by Miller's (now expired) patent moveable bars as improved by Mr. Annan for Mr. Chanter, the proprietor of that patent, that is by making every alternate bar, only, moveable by hand, instead of the whole set, when each adjoining bar moved alternately in opposite directions, according to the mode originally patented by Mr. Miller. These moveable bars, in some measure, answer the same end as the thin bars; that is, of increasing the rate of combustion and, of course, increasing the evaporating power of the boiler, at the expense, perhaps, of a little smoke, which, however, may consist with the most perfectly attainable economical combustion of the fuel.

"Perfect combustion," and the action of a "perfectly smokeless furnace," are very far from being synonymous, or even similar phenomena, and produce very different, and, sometimes, widely opposite results, both chemical and physical, not always likely to be recognised by every noisy patentee or pretender who takes his chemistry like his physic, from the pharmacopœia. In some conspicuous instances, at least, the philosophical jargon employed really encumbers the path of science and progress and, finally, becomes a much greater nuisance than the smoke which these mock-philosophers pretend to subdue.

So far from perfect combustion, and perfect smokelessness, in a steam-engine furnace being identical, they are, very commonly, the antithesis of each other; perfect combustion being the most completely effected when the whole of the oxygen passing through the grate, is the most nearly or perfectly used up in combining with the hydrogen and carbon of the fuel, although it may be occasionally accompanied by the *inappreciably* small loss of a few uncombined atoms of the latter substance in the form of smoke or *soot,* which in fact it is, in a finely divided and impalpable state, merely giving a *black colour* to the nitrogen and other useless incombustible gaseous products of

the furnace. These products *must* pass off, visible or invisible, at whatever cost, although we question, were it possible to collect all the fuel in a large volume of visible smoke many hundreds of miles in extent, whether it would amount to a single ton of coals. A smokeless furnace, however, on the other hand, when the result of a thick fire, thick bars, and slow combustion may, and frequently does, occasion a loss of a large part of the carbon of the coal, which passes off by the chimney, only *half-burned,* in the shape of perfectly invisible carbonic-oxide-gas, thus creating a dead loss of 25 per cent. in coal. This evil, however, admits of prevention in these double furnaces, and by other simple means.

As to the strength of this boiler, the furnace-plates are of Low Moor iron, ⅜-inch thick, the flue and shell, of the same thickness as the best Staffordshire, and the flat ends, ½-inch. The ordinary working pressure of the steam being about 35 lb. per square inch, gives a strain of about 4000 lb. on each square inch sectional area of the iron in the circular part of the shell, leaving a surplus of about 1000 lbs. per square inch greater strength in that part of the boiler, which is equal to withstand a higher pressure of steam by 25 per cent., and we may be still assured that

the boiler is not strained to one sixth of its ultimate power of elasticity, that being taken at about 20,000 lbs. per square inch of sectional area.

One object of adducing this case of a Galloway boiler at such length is to show the propriety of using a much higher pressure of steam than has hitherto been usual, or much practised in marine boilers, as well as the safety of those boilers for that purpose, and it is proper to state that the strength of the plates as above given is now found, after a trial of five years, constant work, amply sufficient for every purpose, with engines requiring steam from 40 to 50 lbs. pressure. This boiler has been, during that time, which may be said to be nearly equal to 10 years' working the ordinary day work in a regular factory, and under the various vicissitudes commonly attendant on night and day working, it has not sustained a single casualty, and not even a leakage of any kind that could be discovered after the most careful inspection. My own personal examination was particularly and frequently directed to the upper end of the vertical tubes where the flame impinges with its greatest intensity immediately after passing over the furnace bridge. This particular part having been pronounced by all practical boiler makers as being

the most vulnerable point in other vertical tube boilers. I, in consequence, subjected it from time to time to the most scrupulous examination; the result on the whole has been so satisfactory that I now venture to recommend this plan of boiler as pre-eminently suited to marine purposes. Should any doubt remain on the mind of any engineer as to the power of the "*elliptical*" flue, as it has been wrongly called, to resist collapse from 150 lb. pressure, that doubt can only apply to the segmental or semicircular portion of its sides,—the flat top, supported by any adequate number of tubes being impossible of collapse; there is one exception which may be stated in order to remove such doubt. And as exceptions sometimes prove the rule, this one will serve to corroborate our opinion, already expressed, as to the much greater strength of this form of boiler than those of the "Pacific," "Baltic," and others with longer vertical water tubes, and which *therefore have the sides of their main flues*, of greater depth, and consequently weaker. The exception is, that only a single case has occurred in the whole range of Messrs. Galloway's extensive practice in the manufacture of those boilers, where collapse in the flue took place, and on that occasion, as appeared from the report of another engineer, was

clearly attributable to this portion of the flue having (from some unaccountable caprice) been made nearly flat, or at least with a very great radius of curvature. The proper curve, however, for this portion of the flue it is very clear should be a semi-cylinder, or a portion of one, of the same radius as the top of the furnace tube, when of the same thickness, they being both subjected to the same pressure.

Besides other and larger boilers on the Galloway plan at the Gutta Percha works, I have also erected several of various sizes at other places, in which perhaps better proportions were attained.

Two such boilers have been working for nearly four years past at the London Zinc Mills more successfully perhaps, and with greater economy than has ever before been obtained with any other description of boiler, under similarly unfavourable circumstances. The dimensions of these two boilers are precisely the same, and are as follows:—Length, 24 feet; Diameter, 7 feet. Greatest diameter of main flue, 5 feet 7 inches, which flue contains 21 vertical water tubes, 11½ in. diameter at top, 6 in. at bottom, and 2 feet 10 in. long. These tubes are three-sixteenths thick, *welded*, and placed zigzag fashion, so that a man may creep easily along each side of the flue, and sweep in

amongst them. The boilers are placed upon a number of fire brick blocks, or short columns, 18 inches high, 9 inches diameter, and 18 inches apart, so that the whole of the lower half of the external shell of the boiler, except where it rests on the columns is exposed to the smoke and hot air in the flame bed. The flame and smoke thus pass through among these columns immediately after passing through the main internal flue tube, and then *dip* underneath the ash pit, in order to pass into the chimney flue. Consequently the products of combustion, after proceeding from the furnaces, make *but one return* to the front of the boiler before passing off to the chimney, which happens to be situated near the front end of the boiler. The fact of the very great economy of these two boilers with this mode of setting, so very opposite to the Cornish, and indeed the too usual system of several returns of long winding flues, to which system it is in my mind utter condemnation, would justify any one, cognisant of this case, to set up such boilers in the direct manner, or without any return flues whatever. This circumstance shows the suitability of these boilers for marine purposes where no external flues can be admitted.

The 4 furnaces of these 2 boilers are each 7 feet

6 inches long, by 2 feet 9 inches diameter, and 2 feet 11 inches deep, composed of Low Moor plates five-sixteenths thick. Each of these furnaces contained 3 lengths of fire bars, each about 2 feet 2 inches long, ½ inch thick, and ⅜ inch spaces between them, making about ⅔ of a square foot area of fire bar surface for each nominal horse power of the boiler, that being called 55 horse.

The external circular shell of the boiler is ⅜ inch thick, and the ends seven-sixteenths of Staffordshire plates, "Thorneycroft's best best crown iron." The flat ends are stiffened by angle irons riveted across from side to side, midway between the flue and the top, and from these proceed stay bars 6 feet long, riveted in a sloping direction to the top of the boiler. Besides these, each end is further strengthened by 4 "gussett" or angular plate stays. The angle irons round the ends are 3½ inches broad, and the rivets are 2 inches pitch. Each boiler is surmounted by a cylindrical horizontal steam "dome" 10 feet by 3 feet, with curved ends, the same thickness of iron as the boiler. This dome is riveted to the boiler by 2 cast iron necks, or short pipes 10 inches long by 8 inches diameter. To these domes the steam pipes are attached. One 5 inches flat disk lever safety valve; and one

glass water gauge is attached to each boiler, but no float gauge nor self acting feed.

These two boilers were employed to drive two 40 horse engines of the ordinary Boulton & Watt's construction, made by Peel, Williams, and Peel, of Manchester; 34 inch cylinders, 6 feet stroke, and 20 turns a minute, working together a little over 200 indicated horse power, which they ordinarily did with less than 3 lbs. of coal per horse power per hour. The steam, being 35 to 45 lbs. in the boilers, is *cut off* by the governor and double beat throttle valve instead of a separate expansion valve, at an average of about ⅓ to ½ the stroke.

It is perhaps useful to mention that the peculiarly sudden action of this double beat or equilibrium valve, when used as a *throttle* valve, has always a tendency to cause priming, much more than the ordinary spindle throttle valve of Boulton and Watt. This, together with the nature of the work carried on, that of rolling thick lumps of metal, called significantly enough "breaking down," and thin sheets called "finishing," where very great irregularity of resistance is inevitable, involves the necessity of keeping the steam very much higher in the boiler than is required in the cylinder; the steam in the

cylinder seldom ranging so high as 20 lbs. per square inch, while in the boiler it is from 30 to 40 lbs. The ever varying resistance caused by these lumps and sheets of metal passing through two, three, or four pair of rolls, at the same time, is one of the unfavourable circumstances for economy before alluded to.

Another circumstance, unfavourable to very great economy in this case, was the draught, which, although the chimney is of sufficient elevation and capacity, was much injured by communication with other furnaces and fire-places, some of them *open* ones. which, without great care in, or *total absence* of stoking or *stirring* the fire, made it impossible to prevent some smoke at particular times, especially after the fire doors had been thrown open, and the furnace too much cooled. Although valves were applied for admitting air at the bridges of the four furnaces of these boilers, by which all dense smoke was thereby entirely prevented for a period of three or four months, and a certificate was obtained from Sir Richard Mayne, the chief inspector under the Metropolitan Smoke Act, to that effect. Yet no sooner was there an occasion to change the fireman, for *a more industrious stoker,* than the smoke again appeared, and the owner was convicted, unjustly, as I think, in a

penalty under Lord Palmerston's Act. It is unnecessary to add that the greatest economy of these boilers in fuel was *before* the Smoke Act came into operation. In addition to this, the situation of the boilers was such as necessitated the "dipping" of the flue considerably, in order to enable it to pass beneath the ash pit, which is well known to be extremely detrimental to draught. Notwithstanding all those drawbacks against the probability of a good performance with, at that time, nearly a quite new kind of boiler, these boilers have continued to work four years without mishap or difficulty of any kind—nearly two years of that time night and day at the same extremely economical rate.

More practical reasons of the like kind might be here given; but what has been already advanced may be considered sufficient to warrant the conclusion that this plan of boiler might at once be applied as a marine boiler, with the greatest propriety and moral certainty of success. For this purpose the boiler will require very little modification from the form indicated by the above description. If any deviation be necessary, I would advise that for 60 or 70 lbs. pressure the diameter should be reduced to between $5\frac{1}{2}$ and $6\frac{1}{2}$ feet, and to meet the exigencies of working with salt

water, besides using the ordinary surface "blow off," and other similar appliances,* we would make all the plates one-sixteenth inch thicker throughout. If required to work nearly or quite up to the maximum pressure of 100 lbs., then all the parts admitting of it should be double riveted, and the rest *welded.*

THE EXHIBITION BOILER OF 1851.

In recommending that the diameter of a high pressure Galloway Boiler should be about 6 feet, it is not without due consideration, and considerable experience of various precedents that I offer this recommendation. One such boiler may now be referred to, belonging to the West-Ham Gutta Percha Co. of West Street, Smithfield, by whom it was bought of the Commissioners of the Hyde Park Exhibition of 1851, where it had been worked during the 6 months

* Lamb's "Surface blow-off apparatus," as described in Murray on "Marine Engines," 1852, or my Boiler Cleaning Machine, as described in my Essay on Boilers in 1838, and first figured in the Artisan Club's "Treatise on the Steam Engine," in 1844, may be used indifferently as they are substantially the same thing intended for different purposes; the object of the former being to prevent *scale,* and that of the latter to prevent *priming.*

that the Exhibition was open. And, although only one of *nine* boilers of about equal power used for the purpose, it supplied as nearly as could be estimated, about one *third* of the whole of the steam used in that building. To young engineers, who usually take theory before practice, it may be as well to state that my reasons, when consulted on the subject, for fixing on 6 feet as the most fitting diameter for this Exhibition Boiler, were, in the first place, that with that diameter, according to the rules already given by me, a $\frac{3}{8}$ inch plate is of ample strength for a working pressure of 40 lbs. per square inch; that being the steam pressure recommended by Sir W. Cubitt, and the other Commissioners, not to be exceeded, and from whom I obtained at last, with some little perseverance, their consent to *exhibit* this boiler, a difficulty created through some mistake, by which four boilers of a different kind had been previously ordered. It was then erroneously supposed that those 4 boilers which were of the multitubular class, though without fire boxes, blast pipes, or large chimney for draught, would have furnished an ample supply of steam for all the purposes of the exhibition; but in this power, as the event proved, they were utterly deficient, not producing even half the quantity of steam required, so that this

Galloway Boiler was considered only as a supernumerary one—a circumstance which gave a very instructive lesson to the railway and other engineers who had the principal share in managing the preparations for working the machinery on that occasion; and the result was that *four additional boilers* had to be supplied in great haste by the same contractor, making in all eight of the multitubular variety, and one Galloway Boiler, before an adequate supply of steam was obtained. Although had the architectural and decorative portion of the Commissioners consented to the erection of a brick chimney, which would have been quite in keeping with the engineering and scientific object of the Exhibition, instead of *nine* boilers, any *three* of them would have been sufficient, besides giving an excellent opportunity of exhibiting a variety of smoke-burning inventions which were thereby virtually ignored. As it was, there was a petty exhibition of locomotive chimneys, a few feet in height—with one exception, the funnel of a marine boiler, only 20 feet high, which in spite of some opposition I succeeded in having erected to the Galloway Boiler we are now describing.

The pressure of the steam being limited to 40 lbs. per square inch, a $\frac{3}{8}$-inch plate will only have a ten-

sile strain upon it of something less than 4000 lbs. per square inch, sectional area of the iron. The formula for the strength of boilers which I usually employ is, $p=\frac{2\,st}{d}$ where s is the strain which, in this case=4000 lbs., t=the thickness of the metal in inches,=·375 or $\frac{3}{8}$, and d=the diameter of the boiler, 72 inches, or,

$$p=\frac{2\times4000\times\cdot375}{72}=41\cdot6\text{ lbs.}$$

will be the pressure of the steam allowable with these dimensions; and I have no doubt whatever that double that pressure might have been put on with perfect safety, so far as the tensile strain on the circular portion of the boiler is concerned.

Another reason for the particular dimensions of this boiler was, that, besides knowing well what a $\frac{3}{8}$ plate will bear, it is so very much used that the proper thickness for securing the best workmanship can readily be obtained.

There needs, perhaps, no excuse for having made this boiler "stronger than strong enough," seeing that it was to be erected in the close vicinity of so many thousands of persons, daily assembled in the Exhibition building, which was, of itself, a matter of no little

responsibility, for it was considered good policy not only to be perfectly safe, but also to enable the general public to feel themselves safe, by an assurance of a surplus of strength so far beyond any possible requirements.

For ordinary commercial purposes, however, where people generally know what they are about, as well as for warlike and other government purposes, where they *ought* to know, if any where, this very inordinate precaution is out of place. And although I have, both by precept and example, recommended, in common with many other engineers, 4000 lbs. for "best" Staffordshire, and 5000 lbs. per square inch strain for Yorkshire iron, as a safe rule to be adhered to by boiler-makers; I am now inclined to modify that opinion. By fixing too low a standard for strength of iron structures generally, the result has been to induce the manufacture of very inferior and low-priced qualities of iron, which are substituted for the best in many situations where detection of the inferior quality is difficult; and, so long as such inferior qualities reached the low standard required for the best, at a much higher price, an inducement is gradually being created among boiler-makers to believe that, in many instances it is only "the *name*

of the thing," which their customers are desirous of paying for. Hence the various designations of "best" and "*best best* iron," although the latter, in some cases, signifies the *worst* of two or three qualities made at the same place. As $\frac{3}{8}$ of an inch is a kind of standard thickness to refer to, and the kind called "Thorneycroft's best crown" is so well known, it is proper to state that, not only has the boiler already referred to been working at from 50 to 60 lbs., but several other boilers of the same kind of iron, same thickness, made by the same makers, and in every way similar, except in being 1 foot more in diameter, (which would be equivalent to an increase up to from 60 to 70 lbs. upon this 6-foot boiler,) have been working nearly the same length of time, and they are working now with perfect impunity, at the same pressure. Those boilers were all tested at the injudicious pressure, in my opinion, of "*three times their working pressure*."

There is an universal prejudice among engineers in favour of this "treble proof" of the strength of a boiler. This Exhibition boiler, for instance, was thus proved, in the presence of one of the Royal Commissioners, at 150 lbs. per square inch, which pressure, in the Commissioner's and the maker's

opinions, was required to justify them in working it at 50 lbs., although, in an ordinary case, 120 lbs. would have satisfied them when the working pressure was intended to be only 40 lbs. Now I am not going to contend that the least injury was likely to be sustained by this particular boiler exposed to so severe a strain; but I wish to point out the absurdity and injurious consequences likely to arise from the prevalence of such a dogma when applied to very high pressures, however safe it has always been at low ones, say under 10 lbs., or, at most, up to 20 lbs. per square inch.

If, instead of moderately good Staffordshire plates, capable, we may suppose, of bearing a tensile strain of 20 tons per square inch section before breaking, we have a boiler to test made of an inferior quality of iron, say only capable of supporting 16 or 17 tons, which was found by Mr. Lloyd to be the ultimate strength of the iron of the boiler of the "Cricket" steamboat that exploded on the Thames, in 1847; and if as was proved by Mr. Lloyd, in that case, by direct experiment on the corresponding boiler, every way similar to the exploded one, namely 5 feet diameter and $\frac{3}{8}$-plates, that the latter was severely strained close to the bursting point, and permanently injured

by the application of 136 lbs. per square inch, giving a reduction of about 40 per cent. for the riveted, below the original, or solid plate, as tested by him, in strips of 2 inches broad. We have only to suppose that our Exhibition boiler had been of the "halfpenny boat Cricket" quality, and if tested at three times the intended pressure, or 120 lbs., which it might have passed safely, perhaps, *once,* and afterwards worked, without suspicion, at 40 lbs., although in reality, *weakened* by the process so much as to become dangerous, even at 60, and it might explode at half-a-dozen or so pounds higher pressure. If such a result may follow such a practice, what, it may be asked, would be a safer mode of proceeding? I answer, from the results of my own practice, as follows; I would have taken a mean point in the above supposed case, between 40 lbs., the working pressure, and the estimated strength of the iron, say 140, which would be at 90 lbs., and make that the point at which to test the boiler. That is not much more than double, in fact, 120 per cent., above its working pressure, namely 50 lbs., as well as being also 50 lbs. below the estimated strength of the iron; and supposing the life (as it is called) of such a boiler to be estimated at 5 years, then this proof test ought

to be reduced by equal instalments of 10 or 15 lbs. each year. Now who will say that, if such a course of procedure, or some similar one, had been made compulsory by legal enactment, before the "Cricket" explosion, that that "accident," and many others, would not have been avoided? But as we are, so far, only dealing with probabilities, we may take the actual pressures used in the "Cricket," namely, working pressure, as proved at the inquest, 66 lbs., the bursting pressure, as proved by Mr. Loyd's experiments, 136 lbs., which gives a mean of $\frac{136+66}{2}$ $=101$ lbs. for the testing point, or about 50 per cent. only, above the actual working pressure. By this, it will be seen how much safer a test of this proportion would have been, than the treble test.

I have stated in a previous work, that a test of double the working pressure was *amply* sufficient, but I by no means wished it to be inferred that such a test should be considered to be necessary, or useful, except at moderately low pressures. In my notes to the edition of "Tredgold on the Steam-engine," published in 1852-3, I regret having overlooked what I consider a dangerous error in that author, although he admits that double the working pressure is a suffi-

cient test for low pressure boilers, he states that "it becomes insufficient in high pressure boilers, because they have a smaller amount of steam room," and actually gives a formula for calculating the excess of strength which he would give to a boiler on that account, saying, "If one boiler contains 20 cubic feet for each horse-power, and another only 10, the boiler with only ten feet of space should be of twice the strength." It is scarcely necessary to point out how TREDGOLD confounds, here, two entirely different objects; one, the prevention of injury to boilers by excessive strain in testing them; the other, the having such an excess of strength as "to provide against accident in the event of the valves being out of order," &c. (Page 268.) Trusting that these remarks may, in some small degree atone for the share I took with others much more competent, in delaying a little longer the descent into oblivion of this heterogeneous work of "Tredgold on the Steam-engine," I shall return to the description of the Galloway Exhibition boiler.

If as I think I have made manifest, this 6 feet boiler of $\frac{3}{8}$ Staffordshire iron, with the ordinary lap and single-riveted, be equal to a working pressure of 70 lbs. per square inch, then it may safely be asserted

that a boiler of the same shape and dimensions of Low Moor or Bowling Iron, one-sixteenth of an inch thicker, and double-riveted, *welded* indeed where necessary, and judiciously stayed, would be abundantly safe to work in a steam ship at the maximum pressure of 100 lbs.

That such a boiler for such a purpose would be very decidedly superior in every respect to any form of marine boiler at present in ordinary use for *large* steam ships, scarcely admits of a question with any one understanding the subject; and those who do not may have the clearest of proofs in the performance of the land boilers I have referred to, as well as that of many others on the same principle, now spread all over the country.

We contend for the adoption of the correct principle which we know that these boilers contain. And as certainly as is the truth of any common rule in arithmetic demonstrable to those who consent to examine the proof, so certain is it in my apprehension that any expedient, which supersedes the present flue and multitubular marine boilers, will very considerably accelerate the passage between this country and America. If this be accomplished even only by a single day of the nine that is yet required, a

great object will be attained for the progress and welfare of the people of both countries. That such an achievement is a point worthy of any man's ambition, we need not insist on—or that of any number of men, on either or on both sides of the Atlantic. To shorten the way to America, by reducing the time now occupied at the rate of only 10 per cent. per annum for the next 4 years, would solve a problem of immense social importance. It would in four years time lay us alongside our friends and brothers in the United States in SIX DAYS! That this will yet be accomplished, there can be little doubt! Experiments in fact are already in progress with this end in view. To reach New York in six days is an object far above any partisan or even national views, nor is the benefit wholly measurable by the pecuniary or commercial advantages attained. For it is by such achievements that nation is to be knit to nation by bonds of undying brotherhood, and the advent is to be hastened of that peaceful kingdom, the clarion of whose renown, and the majesty of whose sceptre, will command the joyful homage of mankind.

On a subject of such vast interest as a material improvement in the art of steam navigation, every engineer, sailor, and shipwright, has some crotchet

of his own. I confess not to be singular in this respect, and some of my plans of improvement have been not confined to paper. They have embraced both engines and propellers, but have principally been devoted to boilers and to *furnaces*. Though certainly I have never been guilty of trying to help a ship on her way to America by *burning smoke,* the miscarriage caused by which was subsequently visited upon unoffending parties.

The merit of that abortive attempt lies with Mr. Charles Wye Williams, so well known for his nostrums in smoke prevention, and the untiring energy, usually appertaining to such adventurers. That a properly constructed *Fire-feeder,* which would supply the furnaces without involving the necessity of opening the fire doors, or admitting air except through the fire bars, would be of great advantage, and abolish the slavery of the stoke-hole, no one can deny. But that would be irrespective of any smoke-consuming or preventive properties it might possess; which, however desirable should not be allowed to engross our first attention. Feeding and stoking the fire, however, have long been accomplished by very simple machinery, on the principles of Stanley and Walmsley, and Miller. All the three inventions are now public pro-

perty; the patents having long since expired; and, alas, the patentees, whom I knew well, have expired also. They were thoroughly practical engineers, and their inventions were entirely successful on land, as they would have been on sea also had an opportunity been afforded for their trial. Those appliances to a suitably constructed marine boiler it is underrating them to say would increase the boiler power of the steam ship by 10 per cent., as they have always done that of the *steam mill* on land by double that amount.

These, and many such equally valuable inventions, not the speculations of mere "science-mongering" amateurs, or paper engineers, but the actual tried and proved productions of practical operative mechanics, lie at hand ready for application to every emergency that can possibly arise in the development of that improvement of steam navigation now so urgently required.

"Where there is a will there is a way," is an axiom in mechanics, as in other things, if *there be money*. As a sample of the mode of proceeding in the choice of an improved boiler, let any plain business man or merchant, he need be neither an engineer nor man of science, obtain a ten minutes interview with

the manager of the West-Ham Gutta Percha Company, at their extensive works in West Street, Smithfield; or let him go to any other factory of which there are several in London, where the Galloway Boilers have been working for several years; for, I perhaps take a liberty in referring to this one more than others, which I have done from its central position in the city, and its having been so well known for many years as the Iron Works of the late Alexander Galloway and Sons, the eminent engineers, formerly of this country, but now of Egypt. He will there see the original Exhibition Boiler at work, which, I have the authority of Mr. Walter Hancock, of the Gutta Percha Company for stating, has been working under his superintendence almost uninterruptedly four or five years since the closing of the Exhibition—a great portion of that time working night and day, and frequently at the extreme range of pressure; this too without any deterioration from use. A few minutes' inspection will bring entire conviction of the accuracy of what we state. The visitor will there see a greater quantity of steam produced by a comparatively small boiler, which might if necessary be fixed aboard a steam ship, and at work in a few days,—at a greater pressure by two or three times over than is now

generally attainable in the present marine boilers. Withal, too, at the cost of a much less quantity of very inferior coal than is at present required perhaps by any other description of boiler, even on land. He will see all this done without the fussing, stewing, and sweating of the present barbarous stoke-hole practice aboard ship, which too many people think a necessary concomitant of all marine steam engines. On the contrary, he will see the work done quietly, with cleanliness and easily; and the black smoke "perfectly consumed" into the bargain, without the intervention of any smoke consuming apparatus of any kind, patent or otherwise; no air being admitted to the furnace except what passes through the fire grate; and he will instantly ask himself, is all this applicable or possible in a steam ship? My answer to such a question is, that it certainly is, excepting merely the tall brick chimney, the want of which would only affect the ability to consume inferior fuel, or the prevention of a little smoke, but which qualities, if thought important, may be easily retained by the introduction of a small blowing fan.

THE ELEPHANT BOILER.

Having disposed of the question, how steam can be best obtained at a pressure, or nearly up to a pressure of 100 lbs. per square inch, and that in boilers with internal furnaces, thereby permitting their use in *wooden* ships where necessary, we come now to the requirements of 100 lbs. pressure and upwards. For this purpose we anticipate the necessity of an iron ship. The reason for this is, in the first place, that to enable boilers, of a given thickness and strength of material, to stand a double pressure; they must be just half the diameter—therefore it is necessary to have external instead of internal furnaces. It is an inevitable law that the strength of the shell of a cylindrical boiler is inversely as its diameter; or in other words, if we find a 6 foot diameter boiler with a $\frac{3}{8}$ shell to stand 60 lbs. pressure, then we may be assured that a 3 foot boiler will stand 120 lbs. pressure, or nearly so, under the same circumstances. In the second place, the full value in heat, from any kind of fuel, cannot be obtained without the intervention of fire brick, or other non-conducting substances, but with which it would be quite impracticable to line the present marine boiler furnaces; or in

fact almost any internal furnace for commercial purposes, although we recollect the case of an iron fire box boiler, erected to heat a new church in Manchester some years ago, having its steam-generating power nearly doubled by simply putting in a fire-brick lining round the fire grate; thus preventing the refrigerating effect on the fuel and flame produced by the close contact of the water-casing and bridge of the fire-box. Many good smoke burners have been made simply by inserting a few fire-bricks in this way—thus as it is called *concentrating* the heat.

By making a small boiler, we make a strong boiler; and by making a brick furnace, we make a hot fire.

In adopting the elephant principle for a marine boiler, we get both these advantages, a small diameter and an external furnace; but, besides that, we get a large width of fire-grate, and the convenience of using firing machines. Moreover, as the resistance is more dependent on the width of the ship than its length, it is incumbent to occupy the entire beam dimensions of the vessel without the intervention of water-legs between the furnaces, if we require the maximum power of the boilers, when they are arranged transversely across the ship. This the elephant boiler

gives us the means of doing with advantage. A range of 3 or 4 boilers may be thus made to occupy the whole breadth of the vessel, with nothing beyond a thin fire-brick wall between the furnaces. The proper physical management of the furnaces is a matter on which far more reliance ought to be placed for increasing the power of steam ships than is dreamt of by any of our "chemically considered" combustion patentees. It is not undervaluing science, but the contrary, to maintain this; in which I shall be joined by Faraday, as I was by John Dalton, when living. To encourage a fireman to work by tact and judgment—not by empirical rule, to become dextrous, watchful and discriminating, is surely of more use than to cram him with the jargon of science, which would leave him as useless a member of society as those who are already thus distinguished. Chemical diagrams, and the atomic system of philosophy, will give little aid in keeping up the steam, and those who are chemists among stokers, and only stokers among chemists, will lend little aid to the advancement of either art.

Although the elephant boiler is, perhaps, more popular in France, and on the Continent, generally, where it was introduced by Woolf himself, many years

ago, it is much used in and about London, principally at flour-mills, being considered a strong and safe boiler, but *smoky;* hence it is often used with Welsh smokeless coal, but it is well adapted to Jukes's, Hall's, or other smokeless fire-feeding machines. I consider that *three,* instead of *two* lower tubes, are objectionable, as they are, in that case, too small to be easily kept clean. Such boilers are not much used in the manufacturing districts, where they are known as "French" boilers; but there are some good examples in Lancashire, the two lower tubes being made large enough for a man to get into to clean. They have been commonly made by Messrs. B. Hick and Son of Bolton, to go with their engines abroad. Some erected by them at Barcelona, in Spain, were of well-considered proportions, being 24 feet long, the main body of the boiler 4 feet diameter, and egg-ended; the two lower tubes each 2 feet 2 inches diameter inside, with only two or three inches betwixt them; the vertical connecting pipes, or water-legs, were 18 inches diameter, and the fire-grate was 5 feet wide by 6 feet long.

The most powerful boilers of this kind I have seen were erected by the same makers, at the "India mill" of Lees, Kershaw, and Co., in Stockport. They are

35 feet long by 5 feet diameter in the main barrel, the 2 lower tubes are 2 feet 3 inches diameter, connecting pipes 16 inches diameter, and 2 feet 3 inches high. The main barrel of the boiler is *flat ended*, and contains a fire-flue 2 feet 3 inches diameter, which is the most objectionable feature as regards safety. Nevertheless, these boilers are worked very satisfactorily with a pressure of 64 lbs. per square inch, and using little more than 40 tons of coal per week. Two of them are capable of exerting about 500 indicated horse-power, driving cotton machinery, &c. They consume about 3 lbs. of coal per indicated horse-power per hour, by means of a pair of compound engines of 8 feet stroke, making 16½ strokes per minute. One engine has the large cylinder 50 in. diameter, and the small one of 23 in. The other engine has the large cylinder of 52 in., and the small one of 25 in. The steam is cut off at 5¾ ft. of the stroke. These boilers occasionally work in conjunction with double-flued cylinder or Cornish boilers 6 feet diameter, with which they contrast very favourably. The fire-bars are ¾-in. thick, and the rate of combustion quick, say 10 to 15 lbs. of common coal per square foot per hour. The draught is produced by a brick chimney, 65 yards high by 6½ feet wide

inside, at top, and 1 inch per yard batter outside. The above data were collected in 1848-9, since which the boilers have been supplied, I believe, with my cleansing-machines, and with Dean's double fire-feeding machines; they have also been covered with felt, &c.: all, of course, tending to produce a still more economical result. I offer this as a sample, and not by any means a solitary one, of the engineering economy of Lancashire, which I would submit to the consideration of my engineering friends in Cornwall, with their lightly loaded engines and superior coal.

I scarcely need add, that none of the new smoke-burning schemes have any share in producing the economy at the India mill, unless Mr. Dean's excellent fire-feeders be classed among such. They, however, do not operate by letting in *cold* air against the boiler bottom, but by keeping it as hot as possible, and the fire-door shut. At any rate, they cannot be said to be benefited by anything that has come out of Lord Palmerston's Smoke Act. At another mill, belonging to the same firm in Stockport, previous to the erection of this one, having three large engines, also, doing about 500 horse-power by 120 tons of bad coal per week, several then well-known plans of smoke-consuming, or prevention, were tried succes-

sively without any appreciable saving of coal; some of them at an expense of some hundreds of pounds. The list of inventors' or patentees' names, as given to me by a member of the firm, comprised those of Rodda, the two Halls, Chanter, Armstrong, and Williams. My own plan, in this selection, it is only proper to state, was the only one that cost them nothing, being a careful system of charging the fires at the back, which I introduced at the same works, the Mersey mills,—then belonging to another firm,—many years previously. This mode of firing is described in one of my "Tracts on Steam," also in the Artisan Club's Treatise on the Steam Engine.

I might here ask what possible objection could be raised against taking so simple and efficient a boiler as above described, and of which the performance can be so easily verified, and place it in an iron steamer, at once, and withal at so cheap a rate, (from £35 to £40 per ton of Low Moor iron,) in place of the present multitubular marine boiler, costing *double* the expense?

In referring to Arthur Woolf as the inventor of boilers composed of systems of comparatively small water-tubes, and which he was mainly conducive to bring into use between 1810 and 1820, it is not to

be understood as applying exclusively to the particular form of boiler *patented* by him. That boiler was, for reasons applicable to most patented articles, not the best specimen of the invention, and it was deficient in proper circulation of the water. Woolf's boilers were really not successful until they took the form of the Elephant, or French boiler, the latter designation being applied in consequence of its being first introduced, if not also first made, in France, by Mr. Woolf himself.

I rather wish to consider him in common with Oliver Evans in America and Dr. Alban on the Continent, as the propounder of a principle of construction of perfectly safe boilers for very high pressure, that of confining the pressure entirely within tubes of comparatively small diameter. That system of construction was almost a necessary concomitant of the introduction of the compound high and low pressure engines by Woolf and Edwards, which engines have been, since their time, extensively made by Hall, Humphreys, Rennie, Hick, and others. The great success of these engines in *extreme* economy of fuel with *extreme* high-pressure steam, has for some time past created a demand for suitable boilers; and that demand has been recently met, in an excellent form

of boiler partly on Woolf's principle by Dunn, Hattersley, and Co., of Manchester. But in which the circulation of the water is more perfect than in Woolf's original plan.

The patent boiler of this firm, termed by them "the Duplicate or Retort boiler," is represented in the annexed cut.

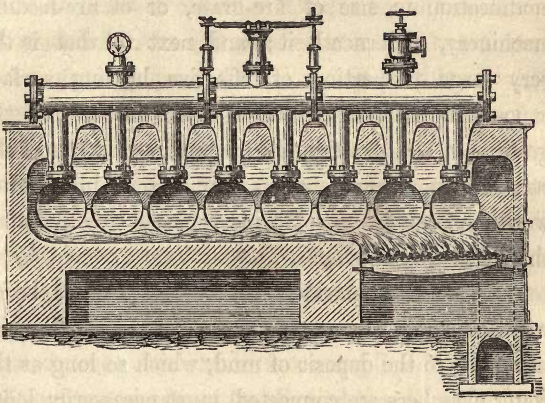


FIG. 1.

It was first introduced to public notice at a meeting of the Institution of Mechanical Engineers at Manchester, and has since been tested to work with perfect safety at 250 lbs. per square inch. One of the retorts, 19 inches diameter having been purposely

pressed until it burst, was found to sustain the extreme high pressure of 525 lbs. before it gave way.

This boiler appears to be formed principally with a view to portability and lightness, for convenient transit, in which it certainly exceeds all others. Besides its great strength, it has, in my estimation, other valuable features, such as its capability of admitting any modification in size of fire-grate, or of fire-feeding machinery, underneath it; and next to that is the very large proportion of effective heating surface exposed to the direct radiation of the fire on the grate. It has also the advantage of admitting of the retorts being *turned over*, as they become blistered or worn over the fire, or of being replaced by others farther off, or by new ones.

An attentive consideration of Mr. Dunn's boiler will discover it to possess some valuable peculiarities in regard to the deposit of mud, which so long as the water chambers are connected, must necessarily lodge principally in a few of the retorts farthest from the fire-grate. The retort at the extreme end will in fact act as a mud vessel or cleaning apparatus for the remainder. A most important purpose will thus be effected, which I hope to have an early opportunity of comparing with previous inventions for the same

purpose before pronouncing a decided opinion. Content for the present in remarking that the same conditions which constitute the last retort of the series an efficient mud collector, also constitute it the most appropriate portion of the boiler at which to supply the feed water, and thereby act as a heater to the latter. To this portion of the boiler Mr. Dunn attaches a cock, or other means of blowing off the sediment frequently. Of mud collectors and water heaters combined there are a great many varieties, among which we may mention that of Mr. E. Green, of Wakefield, as one of the most successful in extensive use; but I have never seen any that in simplicity and compactness approaches this of Mr. Dunn's, and I would say it is applicable to other boilers, the Cornish in particular, as well as the retort boiler, of which it is a component part.

Of cleaning machines that are applicable and effectual in every situation, to all qualities of water, and every kind of boiler, locomotive, stationary, and marine, there is only one variety; that with the *internal* collecting vessels, agitator, and blow-off cock, that can prevent *priming*. And this they do most effectually under all circumstances, if there be room in the boilers to fix them. Nothing can be of greater import-

ance in improving the steam engine than the effectual prevention of priming, and the subject of cleaning machines is on that account alone almost entitled to some future volume of such a work as this to itself.

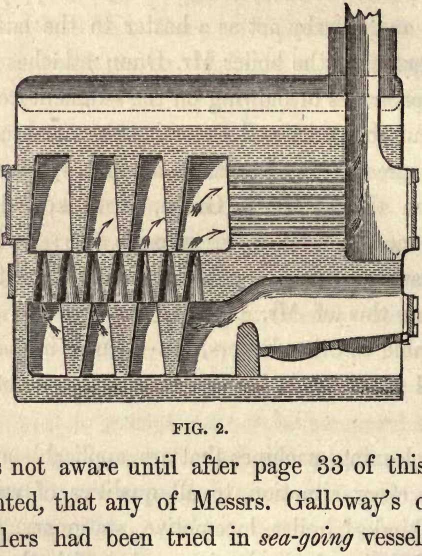


FIG. 2.

I was not aware until after page 33 of this work was printed, that any of Messrs. Galloway's conical tube boilers had been tried in *sea-going* vessels, but learning the fact that some vessels had been recently out to Constantinople containing them, I immediately procured the above sketch from the patent office, which I am informed represents correctly the boilers in question, although not drawn to any precise scale.

CHAPTER II.

SMOKE PREVENTION AND ITS FALLACIES.

WHILE the greatest attention has been given by engineers at all times in advancing the steam engine towards perfection, much less has been done than ought to have been done in improving the construction of the boiler; but least of all has been done for the furnace—the details of fire-grate, the supply of fuel, and the most important of all, the management of the FIRE, upon the proper operation of which much of the efficiency of the machine is dependent. The business of the "stoker," however subordinate and apparently unimportant, cannot long be neglected with impunity; for, like the organ-blower, he will occasionally let us know that the instrument cannot work without him. That portion of mechanical engineering which concerns the architecture of furnaces, has been for so long a period left to the mercy of the operative bricklayer and the ironfounder, who have

both done what they could with large quantities of fire-brick, fire-clay, and thick heavy fire-bars, that it has become, like certain less agreeable portions of another profession we might name, which the regular practitioner commonly endeavours to avoid, but which there are plenty of "irregulars" ready to occupy. The consequence of this has been, as in the profession alluded to, that this important branch of engineering is so much over-run by quacks and pretenders, as generally to excite a considerable degree of contempt in honourable minds for the section of the arts thus degraded. To these phenomena may now be added the natural effect of the recent alteration in the patent law, which has so suddenly overwhelmed the community with swarms of great and little monopolists in every direction, and it is not the least part of the swarm which has settled down upon that opprobrium of engineering, the *smoke nuisance*. On this subject every smatterer on science has a theory of his own to uphold. Nearly every ironmonger is now a patent-furnace monger, and any gas-fitter is ready to fit us with his patent apparatus for "consuming smoke." Advertising quacks, whose business is puffing, are ready to subdue smoke puffs, and promise at the rate of 20, 30, and 40, or any other per

centage, in saving of fuel, by adopting their several nostrums, each guaranteed by hundreds of cut-and-dried testimonials. Audacity in this matter is far from being confined to the needy pretender, but stands out boldly bedizened in the canonicals of science. The style adopted, and the expedients resorted to by these smoke doctors, are worthy of Dr. Solomon, of Balm of Gilead notoriety, or of any other of that band of patriots who request us to beware of counterfeits. The policy pursued is that of *continual reiteration* to induce a belief of incredible statements, or to create faith in such respectability as at least possession of money may give. This we see daily in glaring signboard announcements. Indeed some of the most conspicuous and wealthy of those worthies are known to have competed at public meetings in the provinces, in extravagance of pretension, bidding against each other for public favour, by promising a saving of 50 and 60 per cent!! Of the honesty or dishonesty of such representations, it is needless to speak; but I must state emphatically that, having closely attended to every experiment of consequence in smoke burning for a series of years, I have never yet found evidence of a saving of even 5 per cent. by any plan of preventing or consuming smoke, however

"*perfect.*" And, further, I have found the more perfect the consumption was of smoke, the less was the saving of fuel; or, more properly speaking, a greater consumption of fuel is required in raising a *maximum* quantity of steam *from* the *same boiler* in *the same time,* when the smoke is entirely prevented, than is the case when smoke prevention is not attempted at all. In short, perfect *combustion* is not perfect *economy* in practice, but far from it.

That I have long been convinced of the futility of smoke-consuming furnaces *as a measure of economy,* although I have had, and have still, the strongest inducements of self-interest to endeavour to think otherwise, will be evident, if I transcribe a passage from a work published by me nearly twenty years ago, parts of which had been some years previously drawn up in the shape of reports at the request of various cotton, and other manufacturers, in Lancashire. This work was printed by desire of those gentlemen in 1837, and a second edition was published in Manchester in 1838;* and as it has long been out of print, and as it still expresses my views upon this subject, I

* A Practical Essay on Steam Engine Boilers, as now used in the manufacturing district around Manchester. By Robert Armstrong, C. E.

believe that no apology is necessary for the introduction of the following quotation:—

"SMOKE-BURNING FURNACES.

"In nothing has the philosophical manufacturer or amateur mechanic been so much at variance with facts, and the experience of practical men, as on the subject of smoke-burning. It is perfectly true that the black carbonaceous matter, which usually escapes along with the incombustible gases, and which is the only *visible* constituent of what we term smoke, is all so much fuel; and when *properly* consumed under the boiler is undoubtedly a saving of coal; but it unfortunately happens that the saving is so *inappreciably small* that none who have tried it fairly have been able to calculate exactly its amount, except when it has taken the negative form, which it has most frequently. It is not my intention to speak disrespectfully of any of those who have proposed to save fuel by burning, or '*consuming smoke by combustion,*' as they usually prefer to term it,—for they have generally, if not universally, deceived themselves before they led others astray, as the hundreds of patents for that purpose, and the hundreds of thousands of pounds expended

over them, amply testify. Patent inventors, indeed, of improved furnaces for 'saving fuel by consuming smoke' deserve no small share of public gratitude, from the many opportunities they have given us of ascertaining by experiment a great number of practical data, and useful results, which are now available for other more important improvements."

The pursuit of "smoke-burning," in fact, has been the *philosopher's stone* of the present century. Speculative and practical chemists of the brightest intellects have dabbled in it; such men as Rumford, Watt, Dalton, and Henry were believers in its economy. I cannot speak as to Davy, but it is thought that the predilections of the great living German chemist, who has done so much for the brewing trade of England, lie that way; at least his foremost disciples in this country hold to the yet popular doctrine that *sixty or seventy* per cent. of the fuel is to be saved by burning the invisible carbonic oxide gas, which now escapes from our iron furnaces in Staffordshire.

On this subject I can speak with the more confidence from having had a good deal of practice in directing the application of various patent, and other apparatus and methods, devised to enable furnaces to consume their own smoke in different parts of this

country, as well as in the planning and erection of boilers and furnaces generally in the ordinary way. Up to the passing of Michael Angelo Taylor's act, nearly thirty years ago, which made smoke-prevention in some measure compulsory, little or nothing had been done in the North of England except on the double furnace system of Mr. Losh, of Newcastle-on-Tyne, patented in 1815. It was more successful with chemical stoves, salt pans, and slip kilns in potteries, than with engine boilers. When applied to the latter, it was objected to on the ground that it required a *larger boiler to do the same work,* as well as two fires to do the work of one. I endeavoured to introduce it into Lancashire in 1827, but did not succeed until some years after the patent had expired, when the above objection was found to be untenable. The large boiler proved to be a great advantage, and alternate firing was very economical, independent of its convenience for consuming smoke. My mode of applying it was to place simply a wall of fire-brick longitudinally upon the fire-grate, nearly the whole length from the bridge to the dead plate; but so that both sides could be charged through one fire-door. This method was used in Manchester in a boiler, employed to drive a 40-horse engine, at the Store Street

Cotton Mill, belonging to Mr. Wm. Jones. And I afterwards erected similar divided furnaces at the Worsley Flour Mills, belonging to the Earl of Ellesmere, and at several other places, with some improvements, which consisted mainly in restricting the mid-feather wall to one-half the length of the grate, and making the fire-bars at the front of the grate thinner, and with wider spaces, than at the back. The air was generally let in through the sides of the furnace at about half the length of the grate; but at Mr. Jones's, where there was a good chimney, it was admitted by setting the fire-door ajar 1½ to 2 inches, for 2 or 3 minutes after each firing. In cases where the chimney was low, or had a bad draught from other causes, the supplementary air was forced in over the fire by means of a small rotary fan; and where convenient, this air was in a highly heated state, say at 400 or 500 degrees. In this manner, this species of furnace was worked at the above Flour Mill, continuously with great satisfaction and economy, driving a common low pressure engine working six pairs of 4 feet stones, and other machinery, with about 6 lbs. of inferior coal per indicated horse power per hour. The proportion of the power required by the blowing fan was only about half a horse power. To show the

great advantage of either a good draft, or artificial blast, in all cases of smoke-consumption, it is proper to state here that Williams's patent system was previously tried at the same boiler with the same fire-grate area, without enabling the engine to work half the above load; while the same system applied by the same parties to another, small engine on the same estate, with a *very lofty chimney,* was moderately successful.

The smoke from the chimney of Worsley Mill, when in full work, was *perfectly invisible,* with the exception of a slight vapour during the time that the fire-door was allowed to remain open, but no longer.

The situation of this flour-mill,—a picturesque spot, about half a mile in front of Worsley Hall,—was such that the mill was nearly hidden from view at that mansion, and its existence would have been unobserved except for the smoke which rose above the trees, before the improvement was applied. When the smoke was prevented, the circumstance accidentally coming to the knowledge of the Earl of Carlisle, when on a visit at Worsley, he took the opportunity of convincing himself of the facts as above related, and on their being reported to the Earl of Ellenborough, then first Lord of the Admiralty, that

nobleman at once ordered a similar apparatus to be erected at Chatham Dock-yard. The apparatus was accordingly applied by me to two 20-horse boilers at the Lead mill there, for which purpose I planned the urnaces as nearly as possible a copy of those at Worsley, and the results were very nearly the same. The chimney stood right opposite the windows of one of the royal hospitals, to which the smoke had previously been a great nuisance; but, after six months' trial of the new plan, the chief physician of that establishment reported to the Admiralty the entire removal of the nuisance, and that the health of the inmates had been greatly improved in consequence. This Report was published in the "Health of Towns Gazette," in 1849. And, as I have just been informed by the Superintending Engineer of the Dock-yard, the apparatus has continued to work uninterruptedly to the present time, (1856,) with uniform success.*

* In 1839, I introduced the double furnace system into a steamer, "the William Fawcett," belonging to the Peninsular Steam Company, and she continued to ply with the furnaces thus altered until new boilers were, I believe, introduced a considerable time afterwards. The arrangement of these furnaces differed somewhat from Losh's plan. Each

About the same time several other double or divided fire-grate furnaces were erected, by other parties, at the cotton works of Mr. John Paley, and at other places, in Preston. These were more nearly on Mr. Losh's original principle, having two separate fire-doors and two ash-pits.

Mr. Howard, Mr. Thomas Hall, and a great number of other parties, have introduced various modifications of double furnaces since the date of Mr. Losh's patent, and more or less successfully. The last modification of the kind I have seen, was erected at a small boiler in the Royal Arsenal, Woolwich, by Messrs. Abernethy and Co., Engineers, of Aberdeen, in 1856. The peculiarity of this plan consists in a

furnace had a damper behind the bridge, which could be shut when required, and the smoke produced in that furnace had then to descend through a suitable passage, into the ash-pit of the adjoining furnace, which, by this time, had burned bright, and ascending through the fire, mixing with atmospheric air, it was completely consumed. To maintain the necessary draught an exhausting fan was applied to the chimney. I simultaneously introduced other improvements which very much lessened the consumption of steam, so that, although the boiler was less powerful than before, it was still equal to its work as smaller demands were made upon it. J. B.

jet of fresh air from a pipe on each side of the furnace being admitted alternately, to correspond with the alternate firings by which the smoke from the newly fired furnace is driven laterally, or horizontally, against the bright fire and flame of the other. This is the principle of admitting air patented by Mr. Spibey of Nottingham, several years ago, and extensively applied by him to single furnaces; and by this mode of procedure the injury to boiler bottoms from *cold* air rising upwards against them, at or beyond the bridge, is likely to be avoided. I pass over a great many other plans of double fires, such as Galloway's, Rose's, Fairbairn's, Ormrod's, Hick's, Bristow and Atwood's, and others, as the principle of the whole is nearly the same, and it would occupy too much space to enter into the details.

After Mr. Losh's double furnace principle, the next smokeless furnaces that came into public favour were those of Wakefield, Parkes, Brunton, and Stanley. The two latter being accompanied by, or mainly consisting of, fire-feeding machinery, which was necessarily expensive, came slowly into use, but they were both perfectly well established previous to the year 1827; and the only reason they are not now more frequently met with is, that they are not

well adapted to boilers with internal furnaces. The two former plans, consisting principally of alterations in the brickwork, came more rapidly into use in Lancashire. The smoke-consuming furnaces of Mr. John Wakefield, I believe, had the precedence of the other in point of time, as I had some pulled down which had been erected by him at the cotton-mill of Messrs. Clogg and Norris, in Long Millgate, previous to 1818, and which I re-constructed with my own improvements in 1830. About the same time, several were taken down at Thos. Hoyle and Sons' print-works, Mayfield, and other places, which had been a much longer time in use. In fact, Mr. Wakefield used to complain to me how Mr. Parkes, "having come after him, stole his ideas" of the split bridge, and air-valve at the back of the ash-pit. However this might be, it is certain that Parkes's system became by far the most popular; a great number of furnaces being erected by him all over the country, from 1820 to 1825, after which they were erected by him extensively in France. In the mean time, however, though the plans of Wakefield and Parkes were originally similar, they soon grew widely different. Wakefield persevered with thin and frequent firing, thin and scientifically constructed fire-

bars, well-arranged tools, perforated fire-bricks, for heating and diffusing the air, like Williams, and pigeon-hole bridges; he also paid very great attention to the fireman's art, and he only failed, as he said, from want of it at last. On the other hand, Parkes's system was carried on by him to the extent of enlarging and deepening the furnaces, so as to hold upwards of a ton of coal at a time. This quantity was usually introduced into the furnace during the first two hours in a morning, beginning rather thin near the bridge, and, as it became ignited, gradually increasing the thickness of the charge until within 2 feet of the fire door, where the coal was filled quite up to the boiler bottom. When arrived at this stage, the combustion was entirely that of the gas from the raw coal. The surface of the fire then formed an inclined plane towards the bridge, and as the supply of air through the bars was thus cut off, the combustion was kept up entirely by the air through the air-valve at the back of the ash-pit, and the split bridge, which last was much wider than Wakefield made it, being commonly 3 or 4 inches, or more. During the first three or four hours of the day, the air-valve was gradually closed by the fireman, by which time the diminished quantity of fuel

in front of the bridge allowed sufficient air to pass through in that way. The air-valve was then shut up, and not opened again during the day. The proper action of the fire was, after this, entirely dependent upon the proper management of the dampers, and in the middle of the day the steam was regulated by the admission of less or more feed-water to the boilers.

The above is a programme of the mode of proceeding with Parkes's system at the cotton works of Mr. John Pooley of Hulme, where I had most experience with it, thirty years ago; and it is very nearly the same as the mode carried out at the works of Messrs. Horrockses Miller and Co., of Preston, up to within the last few years.

There is no doubt that considerable economy was obtained by this plan, when very carefully managed, with very low pressure steam and very large boilers, even to the extent of getting an evaporation of 7 to 8 lbs. of water to 1 lb. of Lancashire coal; but it was too unwieldy and cumbrous a system to continue in use more than a few years, excepting at the last mentioned place, where special provisions were made to suit it.

It is not my business, however, in this place, to write the past history of smoke-burning, so much as

*

to describe what is doing at the present time in that direction. With this view, I here insert a brief description of a new form of fire-bar and furnace-grate which I have had in operation for some time past, at different places with very satisfactory results; and I expect to be able to present a more detailed account of the arrangements, accompanied by proper drawings of this and other plans of recent construction, in Mr. Bourne's forthcoming work on the Steam Engine.

UNIVERSAL "ARGAND" FIRE-GRATE.

Like all other furnaces which burn, prevent, or consume their own smoke by an improved combustion of the gaseous portion of the fuel, the principle of this one depends on the admission of a sufficient quantity of fresh air to the smoky flame of bituminous coal, as well as to the carbonic-oxide gas produced by a thick fire of coke or from Welsh coal or other non-bituminous fuel; but it differs from all others in the place of such admission. I do not admit this fresh air at the bridge, although, by that mode, the *disappearance* of the smoke is usually the most perfect, because, when so admitted, it operates as a serious check to the draught, and lessens the power of

the furnace. Neither is the air admitted at or about the fire-door, because, when so admitted, it has a tendency to be drawn between the fire and the bottom of the boiler, thereby cooling a larger portion of the furnace, and diminishing the economy of the fuel. The necessary supply of fresh air to the interior of the furnace is admitted, in this furnace, at an intermediate position between the fire-door and bridge; or, in fact, it is admitted between the front end and the middle of the fire-grate.

This inlet aperture for the air I make through a hollow, or double bearing-bar between the first and second of two or more lengths of fire-bars, and being thus surrounded on all sides by the fire and flame, as in the Argand lamp, it might be called the "Argand Fire-grate," or furnace. (*See Frontispiece.*)

The constituent bars of each series of fire-bars are of different thicknesses, the thickest being placed at the back for *slow*, and the thinnest in front for *quick*, or ordinary combustion,—the thin bars having also the widest spaces between them.

In supplying this furnace with bituminous coal, it must be charged thick on the back of the grate, until the coal reaches nearly, or quite, up to the top of the bridge, gradually sloping forward to the margin of

the air-space; while on the thin or front bars, only, it is fired in the ordinary way.

No complicated apparatus of any kind is required to be attended to, and no additional tools are wanted beyond a "slice" with a blade a foot long, bent flat-ways at right angles, for clearing away obstructions in the air-space. For greater facility in doing this, a modification of the old-fashioned "stoking-bar" is sometimes placed across the ash-pit exactly under the double bearing-bar, but made in the form of a flat plate, and with a raised ledge to serve as a guide to the tool.* No great degree of care is requisite for preventing smoke in this furnace. It is only necessary to throw the coal boldly in,—principally towards the further end of the grate, as a man would fill a cart or a barrow, and plenty of it, closing the fire-door in as short a time as possible, and the smoke will be found to be no darker than from a common house fire, provided the air-space be opened occasionally with the slice above mentioned. If the chimney

* My improved *picker-bar* or "stoking plate" above mentioned is in the case of a bad draught made to turn on gudgeons at the sides of the ash pit by means of a bell crank and rod, so as to check or regulate the influx of air through the double bearing bar if at any time required.

be sufficiently large, which is by far the most important condition, the smoke may thus be made nearly transparent, and, if desirable, can be rendered entirely so, by putting a little damp coal on the front part of the fire, and taking pains to clear out the air-space after each firing.

The above is a *recipe* for constructing a smokeless steam engine furnace, than which it is perhaps impossible to imagine a cheaper or simpler arrangement. But it is necessary again to caution those who would adopt it, or *any other plan* of smoke-prevention by hand firing, that the total area of fire-grate should be at the same time increased by 20 or 30 per cent. beyond what is usually considered necessary with the common smoky furnace, and ordinary stoking. And besides this, there must be always a surplus of chimney power *at command,* by means of the usual counter-balance weight to the damper, suspended in the stokehole within easy reach of the fireman's hand, while engaged in charging the furnace. Without those two provisions, especially the first, times will occur in the case of sudden demands of an engine with a variable load, for steam, when the influx of air must be controlled; otherwise the engine may go slow or stop, and smoke of greater or less opacity will at such

times issue. In the event of the engine going slow from the above, or any other *temporary* cause, just after a charge of coal has been put into the furnace; then it is that the fireman finds a resort to the damper most valuable. When the draught is strong, a slight touch of the damper so as to increase the escaping area will commonly be sufficient to prevent the engine from stopping, or will enable it to recover its speed. In order to estimate the value of a large fire-grate area and surplus draught, it is only necessary to consider what would be the effect under the same circumstances, with a confined fire-grate, and the damper already wide open: there is then of course no resource left but stirring the fire, and consequently stirring up a smoke at the same time.*

* A quick draught is in one respect tantamount to a large fire-grate area, since it equally enables more coal to be burned in a given time, and thus increases the power of the boiler in generating steam. A quick draught, however, has this further advantage, that inasmuch as the temperature of the furnace is higher when the same quantity of heat is generated in a small space than what it will be when generated in a large space, the heat is transmitted much more rapidly to the water of the boiler in the case of the strong draught by reason of the higher temperature in that case obtaining. As therefore there is more heat transmitted in

Having shown how easy it is, with a proper arrangement of the furnace bars, to avoid smoke, it will be useful to show how, with improper arrangements, it is also very easy to do a great deal of harm to the boilers, however perfectly the smoke may be consumed or prevented.

That injury to boilers, and danger from explosions, is to be apprehended from any system of preventing smoke, in which a current of *cold* air is directed against the boiler bottom, is no longer a mere opinion, but a fact which cannot be gainsaid. This will appear sufficiently plain to any one who will attentively read the following copy of a Report of an examination I made of a case of the kind in Manchester several years ago.

the region of the furnace, in the case of the strong draught, there will be less remaining to be transmitted in the region of the flues. In other words the flues will have less work to do, and they may either be made shorter, or the heat will be more thoroughly absorbed.—J. B.

COPY OF REPORT

ON WILLIAMS'S PATENT SMOKE-BURNING FURNACE.

"TO MESSRS. HAMNETT AND CO., CALENDERERS, WATLING STREET, MANCHESTER.

GENTLEMEN,—In accordance with your request, I have carefully examined into the circumstances attending the injury sustained by your steam engine boiler, during the three days' trial of Mr. Williams's patent smoke-consuming furnace, and have to report thereon as follows :—

Some of the plates in the boiler bottom behind the bridge appear to have been exposed to a considerable degree of expansion and contraction alternately, arising from frequent alternations of temperature, by which means the rivets have been dragged successively in opposite directions, until they have become loosened in the rivet holes, and the boiler has become leaky.*

One plate is also what is usually called "burnt out," which is what generally happens when one side of an iron plate is frequently and suddenly heated and cooled, while

* *See* illustrations of similar effects in figures 5 and 7, chap. iii. of this work.

the other side, from its contact with the water in the boiler, is kept at a moderately uniform temperature. In this case, also, owing to the necessarily *laminated* structure of wrought iron, combined with the heating and cooling process above described, "a blister" has arisen in one of the plates, and this blister has been the immediate cause of the giving way of the boiler, by so far weakening it as to allow the pressure of the steam and water to force down the plate in that particular place.

The main cause of the above results is clearly to be traced to the imperfect construction of the furnace, inasmuch as the passage for the admission of fresh air to the flame behind the bridge, is unprovided with a valve or other means of regulating the quantity of air so admitted, or the time of its admission, *within the reach of the engineer* whilst engaged in firing the boiler.

To enable me to explain this point more fully to your satisfaction, I may state that this mode of preventing, or (as it is most commonly called) "*burning*" the smoke, by admitting atmospheric air at or behind the bridge of the furnace, has been long known, and frequently practised in Manchester since it was first generally introduced here by Mr. John Wakefield

more than twenty years ago. This gentleman also practised the method of *diffusing* the air through several small apertures inside the furnace chamber, in the same manner as Mr. Williams. But in all Mr. Wakefield's furnaces, as well as those of Mr. Parkes, that I ever saw, the passage through which the air was allowed to communicate with those apertures was supplied with a regulating valve for the purpose of admitting the proper quantity of air, suitable to the varying state of the fire, or to shut it off at the discretion of the engineer or fireman. And the uniform practice of all operative engineers has always been, when no flame was passing from the fire, and consequently no smoke being made, to shut the air off entirely.

In your case, however, the furnace is so arranged that a constant stream of cold air is uniformly rushing into the main furnace chamber or flame-bed of the boiler *at all times*, and whether there is a flame passing over the bridge or not.*

* I am aware that the production of the invisible carbonic oxide gas, from a thick coked fire, may sometimes create a demand for air when no black smoke is passing. But I contend that such air should be supplied through the grate, and not behind the bridge, unless carefully regulated.

The certain and inevitable consequences of this state of things are, that every time the fresh coal is thrown on the fire, and a flame is produced sufficient to reach *through* the throat of the furnace, the current of fresh air passing directly into [or against] the flame from below, drives the latter right up against the boiler bottom in the manner of a blow-pipe, causing it to impinge with peculiar intensity against that portion of the boiler bottom immediately exposed in the direction of the blast. On the other hand, as soon as the fire on the grate has burned bright, *and the flame does not extend over*

Hypercriticism might contend that, instead of a "stream of cold air," it would have been more correct to say *streams* of cold air, inasmuch as the air was supplied through a perforated plate between two bridges, which did not form, strictly speaking, the split or *double bridge* of Parkes, being much wider apart. These numerous streams, however, united and became one stream after passing through the meshes of the "Patent Riddle," which riddle grating or perforated plate formed the special claim of the patent, and could be of no earthly use, unless indeed it had been used for heating the air. That purpose, however, was especially *disclaimed* in the patent, and the air, in this particular case, was brought in a separate channel at a distance from the boiler intentionally that it might be *cold*, and that all access to it by the engineer might be cut off.

the bridge, the COLD air striking against the same part of the boiler bottom, which had just before been so unduly *expanded* by intense heat, a *sudden contraction* of the metal necessarily ensues, besides a great waste of fuel, and difficulty in keeping up the steam.

I have long paid great attention to the operation of smoke-burning furnaces generally, and more particularly to those constructed on the principle so imperfectly attempted by Mr. Williams, that is, by supplying to the carbonaceous products evolved, their full saturating equivalents of oxygen for effecting the most perfectly attainable combustion of their elements, and thereby preventing smoke, but which can only be safely effected by carefully *regulating* the admission of air to the flame, for which, in Mr. Williams's plan, there is no provision made whatever. I have no hesitation in stating that the result of my experience is, a confirmed opinion against the economy of the process; being convinced, that, in ordinary circumstances, there is more fuel wasted by the admission of cold air to the boiler bottom, than is saved by the most perfect consumption of the smoke. This conviction has been forced upon me by a careful and unprejudiced examination of a great many steam engine furnaces erected both by myself and others, including several constructed by Mr. Williams himself.

I may take the liberty of concluding this report with a caution which I have been in the habit of giving verbally to all those who have occasionally consulted me on this subject for some years past. It is that I have reason to believe that many extensively fatal explosions of steam boilers, not otherwise satisfactorily accounted for, have arisen from similar causes to those detailed above, namely—frequent and sudden alternations of temperature at the lower part of the boiler, inducing a tendency to burst downwards, of which instances are constantly occurring. In fact, in the case of your own boiler, the minor explosion it has experienced, may be considered in the light of a very narrow escape, for if the blistered plate had been of rather a better quality of iron, so as to have held out a few days longer, or until one or two of the adjoining already injured plates had become nearly as weak as itself, in all probability they would have given way simultaneously, and produced an extensive explosion, the effect of which is usually, by reaction, to force the boiler upwards, sometimes to a considerable height through the supervening buildings, in a way that has too frequently created an enormous destruction of life and property.

ROBERT ARMSTRONG.

The reason for giving, perhaps, undue prominence to the above letter or report, is that it was not *originally* published by me,—that is, if printing and giving away a large number of copies may be considered as such—but by Mr. Joseph Williams, of Liverpool, then (in 1841), as now, well known as the proprietor of the patent smoke-burning furnace of his brother-in-law Mr. Kurtz, a scientific chemist of considerable eminence. The letter itself was properly a private business one, which, with other evidence, was, after revisal by me, put into the hands of the solicitor of the firm of Hamnett & Co. for legal purposes. Although not then called on to justify the publication, I did not object to it, because Mr. *Joseph* Williams represented to me the injury his character and that of his patent,—which was for the use of *hot* air,—might sustain in being confounded with those of Mr. *Charles Wye* Williams, whose patent was for the use of *cold* air, owing to both persons having the same surname.* Consequently many thousand copies of the report were printed and circulated by Mr. *Joseph,* setting

* It is remarkable that four different persons of the name of *Williams*, Irish, English, Scotch, and, I believe, Welsh were the holders of smoke patents during the same year. The first and second of whom only we now refer to.

forth the distinctive appellations of himself and Mr. *Charles Wye* at full length. This procedure was also followed by Mr. John Chanter of London, the proprietor of numerous smoke patents, publishing the same thing. The object of both those gentlemen was probably the same, that of demolishing the business of a rival patentee, which, there is no doubt, they did most effectually; raising, at the same time, some rather undignified discussions in the public press on their various claims to notoriety in saving 30, 40, and 50 per cent. in fuel. In those discussions, except in self-defence, I took no part, having no pecuniary interest in any smoke patent, nor any sympathy whatever with any of the combatants.

So effectually had all public interest died out in the above discussion, which was supposed, as usual, by many to be settled in favour of those who care to have the last word, that I did not think it necessary to allude to the subject in my "Rudimentary Treatise on Steam Boilers," in 1851. The subject however, has been revived by the Society of Arts awarding one of its prize-medals for an essay on smoke-prevention, among others, to Mr. C. Wye Williams, who must have convinced the society that, "though beaten, he can argue still." In this prize-essay Mr.

Williams has endeavoured to revenge his former discomfiture by an onslaught on the whole of the present generation of patent smoke-burners, which I do not notice, but for the unfair use he makes of the above report—*misquoting*, garbling, and perverting it in every possible way.* Hence the obligation I am under in giving my report at full length as above.

Considering that, although I stand sufficiently absolved from the necessity of noticing Mr. Williams any farther, there are one or two others whose practical abilities as engineers the public hold in high respect, who have been led astray in this matter of smoke-prevention, but who can have no interest or desire, except to be set right as to facts. I think it proper here to narrate the results of some experiments I conducted upon smoke-burning in 1843, with the view of illustrating some of the points then under controversy. This information is afforded in the following memorandum :—

* See his letter on the smoke nuisance in the Engineer newspaper, for May 30th, 1856.

ACCOUNT OF EXPERIMENTS CONDUCTED AT THE COTTON FACTORY OF THOMAS HOULDSWORTH, ESQ., M.P., IN MANCHESTER, IN 1843, IN ORDER TO DECIDE ON THE ECONOMY OF SMOKE-PREVENTION.

It will be remembered that a select committee of the House of Commons was appointed to investigate the smoke nuisance question in 1843, the results of which investigation were published in a blue book about the end of that year; and on the evidence contained in that and other reports, Parliament afterwards proceeded to pass several new laws on the subject—a very proper thing in itself, if founded upon truth instead of the most erroneous statements to the effect that manufacturers would be greatly benefited by the measure in the saving of fuel thereby ensured.

Among other questionable evidence, by much less reputable parties, published in this blue book, was a statement by Mr. H. Houldsworth, supported by a long array of tables and diagrams, asserting that, "by an admission of air to the extent required to prevent smoke," into the "body" of a steam-boiler furnace, "much additional heat is produced, more steam raised from the same weight of coals, and more water evaporated in the same time." Particulars of

four experiments are detailed in order to show that a gain of 35 and 36 per cent. was "made by admitting air partly at the door, and partly at the bridge, through one of Mr. C. W. Williams's diffusion-boxes," (or patent perforated plates.) In the appendix to the report it is stated that, "in each experiment 1840 lbs. of Knowles's Clifton coals were burnt; a free-burning kind, much used in Manchester. The boiler was one of Boulton and Watt's, 24-horse power, waggon shape."

The following extract is from Table B., Appendix No. 5, page 201, referred to in the evidence of Henry Houldsworth, Esq. *Vide* Q. 1100, page 102, July 27th, 1843.

AIR.	Effect per Minute.		Water evaporated by		Economic Effect.
	Coals burnt.	Water Evaporated.	1840 lb. of Coal.	1 lb. Coal.	
	lbs.	galls.	galls.	lbs.	
No air...	4·64	2·5	992	5·41	106
43 square inch constant aperture	4·68	3·21	1,263	6·85	135
Air, regulated partly by the eye and partly by a scale, varying in some degree with the action of combustion. ..	4·43	3·09	1,280	6·94	134
No air	4·43	2·3	942	5·12	100

The first effect of Mr. Houldsworth's published statement was the industrious propagation by some of the Manchester and Liverpool Journals, of the fallacious inference that 35 or 36 per cent. in fuel was to be saved by smoke-burning instead of 25 per cent. only, supposing his experimental data to be right. That however was denied by many manufacturers, and the result was a request to Mr. Houldsworth to repeat any of his experiments likely to show them so very desirable a result. This after some preparation was agreed to, and I was appointed by the firm of Geo. Clarke and Co. as their consulting engineer to witness the experiment, and was also retained for the same purpose by other manufacturers who felt great interest in the subject.

These trial experiments took place by appointment on the 19th and 20th December, 1843, and the following summary of the results, after undergoing the revision of Mr. Billington, who superintended the experiments on the part of Mr. Houldsworth, and a written acknowledgment of the latter gentleman to their correctness, was transmitted by me to Messrs. Clarke and Co., and the other firms interested in the matter, also to Mr. Wm. Fairbairn and other Engineers, who appeared to be so.

SUMMARY.

Results of the experimental trial of the comparative economy of Mr. C. W. Williams's patent system of smoke prevention and the ordinary plan.

"The exact results of the smoke-burning experiments made at Mr. Thomas Houldsworth's works, on the 19th and 20th of Dec. 1843, are as follows:—

"At one boiler having Williams's Patent Argand Furnace attached—that is with a permanent aperture admitting a *continuous* current of air through a perforated plate or "diffusion box" behind the bridge,—by the consumption of 1150 lb. of coals, the evaporation was 569½ gallons of water in 5 hours 22 minutes;—and on the following day, namely, the 20th of December, 1843, with *the same boiler,* the *same quantity of coals* from the *same heap,* and every thing exactly in the same state as before, except that the aperture for admitting air at the bridge *was kept carefully closed* the whole time, and the holes in the fire door plugged up, the evaporation was 713½ gallons in 5 hours and 20 minutes. The experiments commencing each day at the same hour."

Rate of evaporation per lb. of coal is accordingly:—

With air admitted 4·95 lb. water to 1 lb. Coal.

Without ditto ... 6·2 lb. „ 1 lb. „

Difference 1·25 lb. or 25 per cent. more steam in favour of the ordinary plan and *against* smoke-prevention, instead of 35 per cent. by *parliamentary evidence* the contrary way!

After so signal a failure as the above, what must we think of a statement which the publisher has been influenced by Mr. Williams to insert *twice over* in an unauthorized "Appendix" to a surreptitious edition, miscalled by him the *third* of my "Rudimentary Treatise" to the effect that Mr. Houldsworth had "as a result of his reading Mr. C. W. Williams's book on combustion" reduced his consumption of coal from 20 to 17 cwt. per hour? My answer to this is, that previous to his adopting Williams's system, he was using at the rate of 7¾ lb. of coal per indicated horse-power per hour—full 20 per cent. more than the average rate of other manufacturers at that time, which left room for saving even by the adoption of a bad plan.

Mr. Houldsworth's consumption was not therefore the "ordinary," but an extraordinary and extravagant consumption of coal. This is amply authenticated by various duty report papers of Manchester engines now before me; a fact which constitutes him a very weak authority on the subject, the only nominal (engi-

neering) support he occasionally had in Manchester to the contrary, notwithstanding.

Many other proofs abound, utterly condemnatory of the perfect combustion notion, in its application to steam engines; but as that system is now perfectly defunct, if it ever was alive, except on paper, I shall here conclude with some observations printed several years ago on "perfect" and "imperfect" combustion, for the use of those who require a more rational theory on the subject, and which I now take the liberty of entitling

A THEORY OF THE BEST POSSIBLE COMBUSTION IN STEAM ENGINE FURNACES.

It is true that smoke is a result of imperfect combustion, but it is also true that combustion may be still more imperfect without smoke, and be attended with a much greater waste of fuel. In a steam engine furnace, there never was, and never can be "Perfect Combustion," even in theory much less in practice. In the nearest *apparent* approach thereto, when no *visible smoke* escapes from the chimney, there always arises from a fire of tolerable thickness a certain quantity of unconsumed inflammable gas, chiefly carbonic oxide, whilst at the same time, a very large

proportion (according to experiments by Peter Ewart and John Dalton about *one half)* of the gaseous products passing off by the chimney consist of atmospheric air *unchanged*, that is, containing its full proportion, about one-fifth of oxygen. Now, since it is impossible to increase the supply of oxygen, which by combining with the fuel in the furnace is alone the cause of all the heat produced, without at the same time increasing the supply of the other component of the atmosphere, consisting of *four-fifths* of it, namely, the nitrogen; and allowing, as above, one half only of the oxygen to be available, it follows that about nine-tenths of the atmospheric air admitted into the furnace, and heated to a temperature of about seven hundred degrees, is carried off by the chimney for no purpose whatever, except to enable the remaining one-tenth to support the combustion of the fuel.

An exception may be taken to this on the ground that some part of this waste heat may be recovered by an extended heating surface of the boiler; that, however, is limited in practice by other circumstances, and does not affect the above conclusion as regards the furnace considered by itself.

Whether heat is a material substance or not, which

is immaterial to this question, it is quite certain that in its production from the burning of common bituminous coal, the main elements concerned are carbon, hydrogen, and oxygen, and that the *complete conversion* of these three substances into carbonic acid and ater without waste, is the only common-sense idea that can be conceived of *complete* or "perfect combustion." And, if we could have a continued supply of oxygen without its accompanying nitrogen, such complete combustion might be possible, but as we can only have these two elements *mixed* as we find them in the atmosphere, and one of them having to be separated from the other, as they pass through the furnace, whilst so large a portion as nine-tenths of the whole is of no use in the process, the case is considerably altered.

Take, for instance, any given ordinary furnace, and supposing it to be in operation and supplied with fuel at a given *uniform rate,* if we then suppose the air supporting the combustion to be supplied at a *uniformly increasing rate,* it is certain that a maximum point, in the relative proportions of the air and fuel, must be somewhere arrived at, where the expenditure of heat on the liberated nitrogen and other *incombustible products* escaping by the chimney must coun-

terbalance the heat created by the consumption of that portion of any combustible gas or smoke that would otherwise pass off unconsumed in the same way—the former increasing as the latter diminishes, and *vice versa.*

This maximum point of BEST POSSIBLE COMBUSTION once attained, we can neither pass nor fall short of it without diminishing the temperature and eventually stopping the process; or, in other words, the oxygen which alone supports the combustion, must not only create as much heat as is sufficient for heating itself, but also as much as is required to heat up to the same degree all the air or gases with which it is in contact, otherwise the combustion will not go on at the same rate, and consequently a lessened supply of Steam to the engine results, and less *power,* the only true measure of heat, is produced.

The natural conclusion from the above theory —which is also in strict accordance with all successful experience—is, that the most economical method of firing a steam engine boiler, from which a constant quantity of steam is required, must be by a regularly uniform supply of fuel to the furnace, and a similarly regular supply of air through the fire-grate "and no where else," with a uniform

though moderate emission of smoke, visible or invisible, from the chimney; *visible* within certain limits of density of shade as the combustion is more or less imperfect, being least imperfect when the combustion is quicker and the resulting products contain the largest proportion of carbonic acid gas and steam, holding in suspension a thin grey colouring of carbon or soot, which constitutes ordinary smoke; *invisible* when the combustion is slower and more imperfect, allowing the carbonic acid first formed to be replaced in the escaping products by a large quantity of carbon, in the form of carbonic oxide gas, thereby wasting, at least theoretically, nearly half the available carbon of the coal.

CHAPTER III.

EXPLOSIONS: AN INVESTIGATION INTO SOME OF THE CAUSES PRODUCING THEM, AND INTO THE DETERIORATION OF BOILERS GENERALLY.

How to obtain sufficient strength to resist the disruption of the materials of which boilers are composed is one of the principal considerations usually advanced in investigations respecting boiler explosions. Setting this topic aside, for the present, and dismissing the discussion of theories of explosions, we shall endeavour to collect here the practical results of the most uniform experience relative to the explosions of boilers which are imputable to common causes.

We shall also examine such experiments as illustrate the proper forms and dimensions of boilers in common use, and shall recapitulate the principal sources of weakness arising from ordinary tear and wear, from improper management and from other usual incidents in practice.

AMERICAN EXPERIMENTS ON EXPLOSIONS.

The most authentic illustrations of the inferior limit of the thickness of metal proper for boilers, are two experimental explosions purposely produced in the course of a series of very important investigations, undertaken by a committee of the Franklin Institute of the State of Pennsylvania, at the request of the American House of Representatives, for whom the report of these experiments was first published in America in 1836.

The immediate object of the two experiments in question was "to observe accurately *the sort of bursting* produced by a gradual increase of pressure *within* cylinders of iron and copper." This course was pursued because it had been assumed by many, and indeed the opinion was very generally entertained in this country as well as in America, that ruptures produced in *copper* boilers would not bear the character of explosions, but that a mere *rending* would take place, giving an easy escape to the contents. In pursuance of this investigation, two cylinders were prepared of such a size as it was thought would make a small thickness of material illustrate the question,

"by rending at a pressure which was easily attainable."

In this respect the committee would have found less difficulty if they had made the boilers of a larger diameter; for it appears they really had considerable trouble in causing the boilers to explode at all. However, they did at last succeed, and the results afforded a direct answer to the question between iron and copper, proving the entire want of foundation for the opinion which asserted the superior safety of the latter. Collaterally, also, those results afford good grounds for the first step of a general inquiry into the causes of the explosions of boilers.

EXPERIMENTAL EXPLOSION.

The iron boiler used in this experimental explosion was cylindrical, 10 inches long by 8½ inches diameter, and 1-50th of an inch thick, with ends 1-20th of an inch thick, to which the curved portion was fixed by rivets, nearly touching each other. A single opening in one of the ends of the boiler admitted the water, which was then furnished with a screw, also with a tube and piston, connected with a small spring weighing machine.

"Upon the cylinder of this machine a ring was placed, which was moveable along the cylinder by a slight pressure; this ring was forced towards the end of the cylinder nearest to the boiler head, as the spring was bent, and remaining in its place as the spring relaxed, served to register the maximum pressure to which the piston had been exposed previous to observing it."*

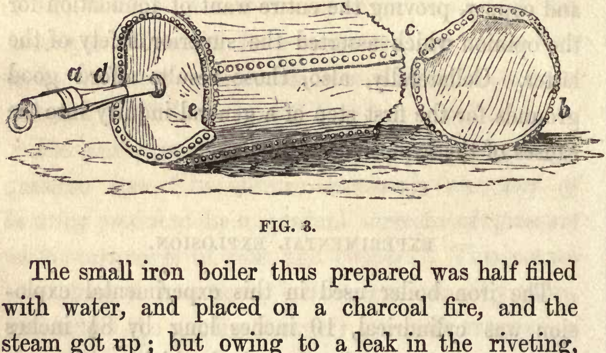


FIG. 3.

The small iron boiler thus prepared was half filled with water, and placed on a charcoal fire, and the steam got up; but owing to a leak in the riveting, the steam escaped so fast that the operators were unable to burst the boiler on the first trial. The boiler was, however, replenished with water, and set lower in the fire, which was again urged, when at last, with some difficulty, an explosion was produced.

* See the original Report, page 66. p 18] this book

So little dependence can, in general, be placed on the relations made by witnesses of accidental explosions, and so rarely have explosions been intentionally made for the purpose of illustrating this question, that, for the sake of accuracy in preserving all reliable facts, the different members of the committee simultaneously addressed their attention to the different circumstances which had to be observed at the time the explosion took place.

"Part of the committee were engaged in observing the progress of the experiment at this moment. The fire was near the middle line of the boiler,* burning not strongly near that line, but very rapidly below the boiler; the steam issued freely through the leak before alluded to, and the whistling sound which it produced, and *which had increased gradually in strength,* as the experiment progressed seemed constant. The length of time during which the steam had escaped showed the water to be low, and induced the supposition that a second time the object would fail; when an explosion occurred."

* As the boiler rested horizontally in the fire, and was half filled with water, this middle line and the water surface would nearly coincide.

THE CROSS-LANE MANCHESTER EXPLOSION.

After recounting the incidents of this case of artificial explosion, I shall now proceed to describe some of the cases of real explosion which have occurred in practice. One of these cases is that of an explosion which took place several years ago, by the bursting of a small cylindrical boiler, of about three feet in diameter, used for the purpose of working a six-horse non-condensing engine, at a pressure of 60 lbs. per square inch. It had *two safety valves*, each of about a square inch area, and both were stated to be in full action at the time the explosion took place, having commenced blowing off steam a few minutes before.

The result of this explosion was, that the wrought-iron end of the boiler next to the furnace was torn away, principally by splitting the angle iron, which was barely $\frac{3}{8}$ of an inch thick, and thrown more than 20 yards off, carrying the fireman six or seven yards of that distance, who, together with another man, was killed on the spot. The body of the boiler was driven in a contrary direction, through both the external walls of the engine-house, one nine and the other fourteen inches thick, at the same time carrying away the

steam-engine itself several yards into a field, at the other side of the building.*

THE JERSEY STREET, MANCHESTER, EXPLOSION.

Another apparently similar kind of explosion to that just described, took place in October, 1841, at the Machine Manufactory of Messrs. Elce and Cottam, in Jersey Street, Manchester. This boiler, like the previous one, was employed to drive a six-horse high pressure, or non-condensing engine, having an eight-inch cylinder and a two-feet stroke, working usually at a pressure of from 26 to 36 lbs. per square inch. The safety-valve, which was of the common kind, with a *packed spindle and stuffing-box,* was adjusted by means of a Salter's spring gauge, to blow off at 40 lbs., beyond which pressure it could not be screwed down.

This boiler was a cylinder of 9 feet 6 inches in

* This explosion took place in October, 1832, at a saw-mill in Cross-lane, Manchester, belonging to Mr. George Jones. The engine and boiler were both quite new, having only worked a few days, although at the time of the explosion the engine had been stopped for a few minutes for the purpose of adjusting a strap on the machinery.

length, with flat ends, 3 feet $10\frac{1}{2}$ inches diameter. It was made of good iron, $\frac{3}{8}$ inch thick all through, and had been some few years at work. The two ends, or as the Americans call them, "heads" of the boiler, were braced to each other by one longitudinal wrought iron stay bar through the centre, attached at each end by a wrought-iron strap and cotter. It was the giving way of this strap, against which the cotter was driven, through a slot in the stay bar, in the usual manner adopted for low-pressure waggon boilers, which was the *immediate* cause of the explosion. The strength of the iron, however, at the place of fracture, when examined by good judges, was pronounced to have been capable of resisting a pressure on the end of the boiler of at least 100 lbs. to the square inch.

STICKING OF SAFETY VALVES.

That the support above mentioned should have given way when the safety-valve was free to open at 40 lbs. per square inch, or less than one-half the pressure that it was proved to be thoroughly able to sustain, is one of the anomalies we are so frequently meeting with in these investigations. I would here call attention to this point; because nothing would be

easier than to make short work of such cases, by saying that the safety-valve must either have *"stuck or jammed,"* or otherwise must have had additional weight put upon it at the time. This, in fact, was the conclusion come to by three practical engineers of the highest eminence, who agreed to deliver to the coroner's jury a joint report on this case.

This *sticking* and *jamming* of safety valves, is, in any case whatever, so extremely improbable, that a resort to this explanation, without actual proof of its existence, is much to be reprehended. In this particular case, it is true the safety-valve was found broken off and blown to a considerable distance, having its spindle somewhat bent, and it had been wrapped with a certainly improper packing of hemp; but even if the bending of the spindle had been done previously to the explosion, (which was in the highest degree improbable) the "sticking" thereby created in the packing, could not have added many pounds per square inch, to the resistance offered to the free escape of the steam.*

* NOTE BY AN EMINENT GOVERNMENT ENGINEER.

"I fear that it is difficult to say what amount of force is sufficient to raise a safety-valve whose spindle is bent, and therefore I would suggest that 'a measure' be not as-

Not a much better stalking horse than this universal sticking point is the criminal overloading, or *"making fast"* the safety-valve. Any imputations of this kind without the most clear and positive evidence, both direct and circumstantial, is simply begging the whole question. There is very rarely, except in the case of locomotives, any inducement to do any thing of the kind, but very frequently the contrary, as was very likely to be in the case before us. For the engine had not started, and from the proved careful habits of the engineman who was killed by the explosion, it is much more probable that he *opened* or eased the safety-valve, by removing all or part of the load upon it, and my firm conviction was, at the time, that he did do so, and that the boiler blew up on the instant, or in a few seconds afterwards.

signed. "I know a very serious case of rupture of a new boiler, attended with loss of life, which was solely attributable to a bent spindle, in my opinion, * * * but I must confess that this conclusion,—mine as well as yours, being matter of opinion, simply, might be taken indifferently, according to the notion of the reader.

"I agree with you that '*sticking*' of safety-valves, properly so called, is extremely improbable."

DEFICIENCY OF WATER.

In the Jersey-street boiler, as well as in that at Cross-lane, might be seen distinct traces of the water having been too low. There were certain marks left by the sedimentary deposits all around the interior of the boiler, showing the high and low-water marks. These indelible water lines gave evidence unmistakeable, that the water had been too low. Since my attention was first directed, many years ago, to these peculiar high and low water deposit marks, I have personally inspected the internal condition of many hundreds of steam engine boilers, and I have missed no opportunity of testing the accuracy of these indications of water level, by a reference to other well-ascertained facts, and have found that mutual accord which was to have been expected.

In the Jersey-street boiler, some of the most distinct, and probably the most recent of those water-marks were within twelve inches of the boiler bottom, at which point, and at least an equal distance below the proper level, it is extremely probable the surface of the water was, when the explosion took place.

Now, it is to a deficiency of water to this extent, combined with a sudden opening of the safety-valve, causing a rapid ebullition, and a spreading of the water over the super-heated side of the boiler, that I principally attribute the frequency of explosions.

COMPARISON OF THE AMERICAN EXPERIMENTAL EXPLOSIONS WITH ACCIDENTAL EXPLOSIONS.

We may now return to the American experiments, with the advantage of the illustrations afforded by the two Manchester explosions, in which, in the words of the committee, the "sort of bursting" produced in each case, was precisely of the same kind.

In the American Report, speaking of the iron boiler, it is stated that "the explosion tore off one of the heads *b c* (Fig. 3,) of the cylinder, projecting the other parts of the boiler in an opposite direction, carrying with them, a portion of the distance, the iron cylinder forming the furnace, and scattering the fuel in every direction.

"The report attending the explosion, resembled that from a small mortar fully charged, the steam mixed with the smoke was not considerable in quantity, and few marks of water were to be seen. The boiler head

was thrown 15 feet, the boiler and spring register about 6 feet, and the furnace, weighing about 45 pounds, was overturned and carried 4 feet. The pressure indicated by the register, was $11\frac{1}{4}$ atmospheres, (about 154 lbs. per square inch.)

"In examining the boiler, it appeared that the head *b* which was thrown off, had first struck against the iron furnace, which had deflected it outwards; this is shown by the indentation *c* in the figure. This head was forced off all around, in the line of rivets which attached the head to the boiler, the metal remaining between the rivets being less than the space occupied by them."

The accompanying figure (4,) will give an accurate idea of the appearance of the boiler after its rupture.

LOSS OF WATER BY BLOWING OFF AND LEAKAGE.

The Committee then goes on to give the details of an experiment with a *copper* boiler of the same diameter, and of similar construction, which was exploded by a pressure supposed to be of about sixteen atmospheres, after having failed in the first attempt owing to leakage, as in the former case. The sound or report was stated to be like that from an 8-inch

mortar. The copper was torn from the heads, unrolled, and irregularly bent; adhering to the heads for only a short distance, as shown in the cut (Fig. 4), and the heads were bent outwards. The thickness of the copper at the line of rupture, varied from ·025 to ·035, say about 1-32 of an inch.

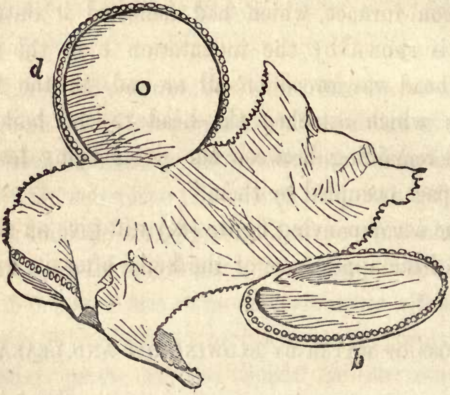


FIG. 4.

The description of the above carefully recorded experimental explosions, shows that the steam was allowed to rise gradually, in both cases, until the boilers gave way. This gradual and *slow increase* in the pressure of the steam, *was in great part caused by the leaks impossible to be avoided in the riveting of*

such very thin boilers; a circumstance which enables us to compare these experiments with other experiments at boilers under different circumstances, but in very similar conditions as to leakage of water and steam, which we so frequently meet with in ordinary practice. A not very dissimilar condition is that of the continued escape of steam, from the safety-valve or otherwise, and the consequent loss of water during the time an engine is standing, and the force-pump not at work, such as has been already described in speaking of the Cross-lane explosion. Another instance, is the case of a Locomotive when running on a railway with the steam either blowing off, or being continually consumed by the engine at a pressure or strain upon the iron very much greater than either of the Manchester explosions we have described, but with this important difference, that while the locomotive is running, the full supply of water is easily kept up. In nearly all explosions of locomotives that have hitherto occurred, which have been very few, and of these only a very small number have taken place while the engine was running, there has been always good reason for assuming a deficiency of water in the boiler.

There is another condition that admits of a com-

parison with the American explosion, and which is, perhaps, the most important of any yet enumerated. It is the condition of an ordinary stationary boiler when the water surface is allowed to become too low from unseen leakages at the *lower* part of the boiler at certain times when the engine is standing, and consequently the feed pump not at work. It will be well to bear all particulars of frequent undue leakage in mind for future application, as they have an important bearing on the general subject of boilers in other respects besides those above named, and they have been entirely overlooked by the American committee.

It appears that both the American boilers exhibited proofs of the water having been too low at the moment of explosion. Speaking of the copper boiler, the report says :—

"The marks of the sediment remained in the boiler, and indicated that the water was about *an inch deep* when the boiler exploded." Much more steam being formed, and more water left, at the moment of explosion, in the copper than in the iron boiler. It was also observed that the steam increased "more rapidly as the quantity of water diminished," and the committee add the following remark as a conjecture :—

"It is possible there may be a relation between the space occupied by the water and that in which the steam is formed, most favourable to the production of steam, and when this was attained, a rapid rise of elasticity took place."

It is much to be regretted that no further experiments were instituted in the direction of this sagacious suggestion. The committee, however, were under the necessity, from the nature of their instructions, of investigating some particular averments of Mr. Perkins, together with some episodical refinements that seemed to have little connection with the great facts they were in quest of. In reading the above passage in italics, in the report, and knowing that this branch of the inquiry ended there, it is difficult to help lamenting that it is as if Columbus had turned back when he was within sight of land.

Nothing remarkable occurred previous to the instant of the explosion of the copper boiler, and the members of the committee employed in the experiments were engaged in observing the boiler at the instant it exploded. When "a dense cloud of smoke and flame, capped by steam, rose from the pit,* the

* See note A at the end of this chapter, concerning the explosion of a large boiler at Bolton, Lancashire.

stones and combustibles were widely scattered, and the boiler was thrown in a single mass about 15 feet from the furnace."

This copper boiler was rent in the manner shown in the figure (fig. 4), giving way in an irregular line, just above the probable water line on one side of the boiler, but not conforming to it. The lowest points of the two heads of the boiler before the explosion were at *d* and *b* (see fig. 4, page 134).

CONTRARY CONCLUSIONS DRAWN FROM THE AMERICAN EXPERIMENTS.

The American committee conclude their remarks on these experiments generally, by observing that "all the circumstances attending the most violent explosions may occur *without a sudden increase* of pressure within the boiler." This, no doubt, is true as a *possibility*, but it does not appear to me to express correctly the circumstances usually attending explosions in practice. The committee indeed do not say that it does do so, but such a conclusion is a natural inference from their averments. My experience, however, and a generalisation of all the facts which have come under my observation during a

large practice in boiler engineering, conduct me to a different conclusion. My opinion is, that, *in the most violent explosions that have occurred, there is always a concurrence of circumstances attending them, which show that a sudden increase of pressure within the boiler has taken place, either at, or immediately before, the moment of explosion;* and further, that, without such concurrent circumstances, or some of them, the explosion would not have taken place at all.

COMPARISON OF CONCLUSIONS.

If we briefly express the conclusion of the committee in similar terms to those used in the enunciation of our own theory it amounts to this, namely, that *all the circumstances calculated to produce an explosion may "occur" without an explosion taking place.* While, in opposition to this, I maintain that those same circumstances cannot "occur" *simultaneously* without an explosion being produced.

Considering both these conclusions as separate propositions, and one or the other to be proved by its general agreement with facts as they arise in other cases that come before us, we may begin by taking, as an instance, the first experiment with the iron

boiler as given by the committee. Here there can be no doubt that all the circumstances which *they considered* to be necessary to cause an explosion existed, and yet no explosion took place. We, however, hold that no *sudden* increase of pressure took place, and therefore it was that, in the first instance, no explosion ensued. Thus we see that one of the most important circumstances is wanting. Let us however see what all the facts were, by which circumstances were so constituted as to fail in producing the explosion. In the first place, the boiler was without a safety-valve, unless the leak in the riveting may be considered as having the effect of an imperfect one. Secondly, the water surface was proved to be *considerably below its proper level,* and therefore the upper portion of the sides was exposed to the risk of becoming overheated.

Now, here are facts constituting two predisposing causes,—the shutting up the steam and the deficient depth of water. But the first was confessedly imperfect, the leak allowing the steam to blow off, from the commencement of the experiment, so fast that it could not be raised to the bursting pressure, even gradually,—not a bad illustration, as the result proved, of the *safety* of a badly fitted safety-valve,

or one in bad order, not tight. And the other fact, we may also show, was only imperfectly calculated to produce a *sudden increase of steam-pressure,* in the only way that such a thing can be conceived to be possible; that is, by the water left in the boiler being, by some impulse, put bodily into motion, and caused to flow over the over-heated metal. That the over-heating of the sides, to some extent, took place, there is no reason to doubt, although there is great reason to doubt that the quantity of water left in the boiler was sufficient for overflowing entirely the over-heated part, even if such impulse had been given to the mass of water as would have arisen from a slight increase or enlargement of the leak, and which a little increase in the pressure from a more rapid production of steam would have produced.

CONCURRENCE OF CIRCUMSTANCES ATTENDING THE FIRST EXPERIMENTAL EXPLOSION.

Now let us examine what changes of circumstances were made at the second trial with the iron boiler when, at last, an explosion did "occur." The Report states that the boiler was "replenished with water," and we may safely infer that it would not be scantily

replenished, seeing the Committee considered the previous deficiency to be the cause of the failure of the first experiment, or, at least, one cause of its requiring to be repeated. Then the boiler was "settled *lower into the fire,* which was again urged," and the whistling sound of the steam through the leak, which before had increased, "seemed constant." Soon after this, the explosion took place.

Here we cannot fail to remark, that the two main circumstances, contributing to bring about the explosion, the pressure and the low water, were present in the same degree, or nearly so, as on the first trial; although the pressure might be a little higher, and therefore calculated to produce, as it certainly did produce, an *enlargement* of the leak or fracture in the riveting; which enlargement, in its turn, became the *third* or *actuating circumstance* which, concurring with the other two, caused the explosion of the boiler to take place on the second trial.

The reader who has followed me thus far, will now be in a position to enable him to make a practical application of this reasoning to the case in hand.

PRACTICAL APPLICATION OF PRECEDING PRINCIPLES.

Settling the boiler "lower into the fire," besides raising the pressure of the steam higher in the same time, would also, from the increased expansion of the over-heated plates, tend to diminish the leakage, thus diminishing the waste of water and lowering the water-level more slowly, consequently giving more time for the sides to acquire an undue degree of heat from the nearer proximity of the fire.

The proved effects arising from overheating the sides, or other parts of a boiler, to a temperature of from 400° to 500°, are now well known to be—first, the repulsion of the water from the overheated surface, producing a *decreased* amount of steam; but immediately afterwards, as the temperature of the metal is reduced down to the point of maximum vaporisation, or a little below 400°, by *any thing causing the water to flow over the overheated parts*, a sudden and greatly *increased* production of steam. Now, had there been a safety-valve attached to this experimental boiler, and had it been suddenly opened either by the pressure of the steam or by design, this

flowing of the water over the sides would have taken place, according to the theory here enunciated, precisely in the same manner as it was in reality produced by a *sudden enlargement of the leak* or defect in the riveting; and from which the rent or rupture of the whole boiler might have proceeded instantaneously. The enlargement of the leak in this case, which a slight increase of pressure was sufficient to effect, may in fact be compared to the pulling of the trigger of a gun overcharged, and ready to go off. Thus also, according to my views, a good safety valve, if brought into action, would have accelerated the explosion of this boiler, or rather have caused it to take place during the first trial. The opening of any ordinary induction valve for blowing through, for the purpose of starting an engine, or any other sudden liberation of the steam, from any cause whatever would have had the same effect. Any thing in fact tending to a disturbance of the equilibrium, or level of the water inside the boiler, would have answered the purpose. This disturbance we are bound to believe was effected by the rending of the boiler at the leaky or defective seam of rivets on the second trial, which caused the rise of the water level over the hot metal, and a consequent sudden production of steam, by which the explosion of the boiler was finally produced.

RECAPITULATION.

Respecting the peculiar phenomena relating to the repulsion which takes place between highly heated metal and water, known of late years, as the "*spheroidal* condition of water," and which I consider one of the corner stones of my theory of explosions I shall speak more at length in another place.* At present it will suffice to recapitulate the circumstances already mentioned as among the most prominent causes of boiler explosions.

First,—The overheating of the boiler bottom or sides, or the tops of the internal flues or furnaces, which may be brought about by the water level becoming accidentally too low. The bottom of the boiler, however, may become overheated from many causes without any undue depression of the water level. One is the interposition of indurated sediment, furr, or scale, between the water and the metal. Another is the operation of a powerful blast or draught through the fire, by which such a quantity of steam is generated over a small portion of the boiler bottom, that the water is partially or wholly driven

* See Note B at the end, on the "spheroidal" condition of water.

away or repelled therefrom, in the "spheroidal condition" referred to; and is often *produced by currents of air for smoke-burning purposes, admitted in an injudicious direction.*

Secondly,—The giving way of some small portion of the boiler, which would not of itself constitute an explosion, but which would be sufficient to liberate a large quantity of steam or water, and create a sudden disturbance of the water level, which circumstance, concurring with the other conditions named, a sudden rise in the pressure of the steam would result, and an explosion ensue.

DEFECTS PECULIAR TO BOILERS COMPOSED OF RIVETED PLATES.

Ordinary observers sometimes make the remark that, in comparison to the frequent instances of boilers bursting, we seldom hear of the bursting of guns; and among sportsmen, never perhaps unless overcharged. Without noticing the truth of the allegation, which is perhaps not quite admissible, there is one circumstance which renders the comparison unfair towards the boiler. A gun, a fowling

piece, for instance,—though said to be in constant use for a whole day, is only subject to pressure for a fraction of a second at each discharge, not in all occupying many minutes, whereas the boiler has to resist the pressure, and its variations continuously. The general cause of the explosion is the same in both cases. The boiler like the gun is too weak for the charge it contains *at the moment of the explosion.* "Why then," it will be objected, "can you not do as the gunmakers do—make your boilers stronger, with an ample margin, for covering errors of calculation, and unseen defects in the material; and then, after a *double* or *treble* proof, ought not a boiler to be as safe at least as a gun?" This semi-military way of putting the question, is the language, and conveys the notions, not of military but of many civil engineers and boiler makers of the highest practical talent, and therefore deserves a categorical answer.

In the first place, putting out of consideration *cast iron* boilers, because they are now seldom or never used, although much might be said in their favour, I answer that a boiler *composed of plates* of wrought iron *rivetted* together, and overlapping each other at their edges, is in a very different condition to a gun or cannon composed of one nearly uniform piece of

metal. The latter quickly acquires a uniform temperature after any disturbing cause, and a more uniform contraction or expansion throughout its whole substance is the result. The boiler, however, is necessarily exposed to much greater inequality and extremes of temperature; it is consequently liable to correspondingly greater variations of expansion and contraction; and it will not be difficult to show that the great contraction and expansion of this compound and complicated structure of plates and rivets forming the boiler, and which is going on continually while the boiler is at work, as necessarily tends to tear it in pieces, even without much assistance, from the pressure of the steam.

As an example, in order to illustrate the destructive effects produced by the continually varying expansion and contraction going on among the plates of a riveted boiler, I may take the common case of one 20 feet long by 6 feet diameter, with the fire under its bottom, and containing an inside tube or flue. Both boiler and flue being composed, as is usual, of, say 10 rings of plates of about 2 feet long each.

Now, on the first application of the fire to the bottom of such a boiler, and before there is any

ressure of steam at all, each of these plates immediately acquires some intermediate temperature between that of the fire outside and the water inside the boiler. These two temperatures may be fairly considered to average about 1500, and 100 degrees respectively to begin with. The external surface of the wrought iron plates where single, and the whole substance of the outside portion of the plates where *double* or *lapped* over the other, tending to the higher, and the inner surface of the boiler bottom tending to the lower temperature. The consequence of this is that the expansion of the outer, exceeding that of the inner surface, the boiler bottom becomes to some extent *convex outward,* or towards the fire in a longitudinal direction; thus,—

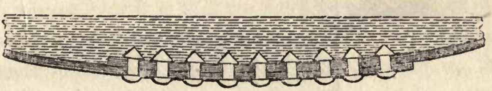


FIG. 5.

The curvature of the plates is purposely exaggerated in this figure in order to show more clearly the form the boiler bottom *tends* to assume theoretically, and not its extent; on the application of the fire every time the steam is to be got up; and this on the assump-

tion that the joints of all the plates are perfectly and firmly riveted, and each plate of *exactly equal strength throughout.* This however may be considered an almost impossible condition in practice. There is always some one or other of the seams of rivets less capable of affording resistance to the immense force of expansion than the rest, and these parts will therefore be the first to give way. The consequence is that the boiler bottom more generally assumes the form represented in Fig. 6.

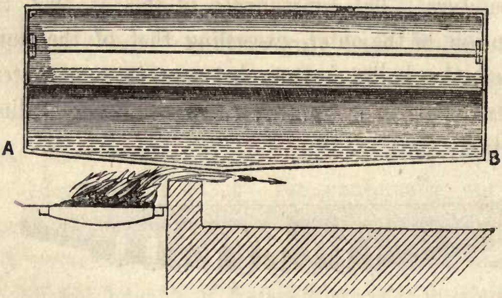


FIG. 6.

Should there be any pressure of steam at all in the boiler, and the plates be of equal strength, and equally acted on by heat, of course the point of greatest depression would be near the middle of the length of the boiler. The greatest heat, however,

being in the vicinity of the fire-bridge, is sufficient to determine the position of this point at the nearest seam of rivets to the bridge; and there in fact this depression is usually found. When permanent, it is then commonly said by the stoker, "The boiler bottom has come down." *

* Although this expression is usually applied to waggon-boilers, the case is in point of fact one of *collapse*, similar to that of a large fire-tube of a Cornish boiler. The subject is treated on more at length in my "Essay on the Boilers of Steam Engines," 1839, page 241.

As this work has been several years out of print, I give the following extract from a *second edition*, which I have had some time in preparation, together with an additional volume of "Notes and Illustrations."

"It may be asked, if our theory of steam boiler explosions be correct, how it is that we have not many more of them, as the causes to which they are ascribed may seem to be of almost every-day occurrence? The answer is, that the *bursting of boilers* is also a matter of every-day occurrence, to an amount which the public generally are altogether ignorant of. To be sure these burstings are not generally called *explosions*, although in reality they are so, being different only in degree. It would not be difficult to prove that two or three of these minor explosions occur in Manchester every week; but when no fatal consequences ensue,

With respect to the extent of the depression liable to be produced from this cause. If we take the difference of temperature between the external and internal surfaces of the boiler bottom, at 500°, and allowing iron to expand at ·00007 of its length, for every 10° of Fah., or $\cdot 00007 \times 50 = \cdot 0035$ of its length for 500°, this will correspond to ·84, or nearly an inch of expansion in the total length of the boiler bottom externally.

The immediate action of the fire is, of course, to bend each plate separately, supposing the latter to be

and no particular damage is done to any adjoining property, of course the circumstance never gets into the newspapers, and no public notice is taken of it.

"Usually, the affair has quite another name when it occurs with a waggon-boiler; it is then said that the "boiler bottom has come down;" in other words the concave bottom is forced down into a convex form, and sometimes the sides are in like manner forced outwards, about the middle of the length of the boiler. The consequence in the least violent of these cases is, that the boiler is lifted up a few inches from its seating by the bottom striking upon the top of the fire-bridge. We also usually find every seam of rivets violently strained, so that the water runs through the boiler-bottom like a riddle, although there is seldom a hole of more than a few inches in area." R. A.

clean. But a boiler has commonly some sediment deposited from the water, and any of the ordinary deposit, however thinly spread over the bottom of the boiler, being a very bad conductor of heat, permits the temperature of the plates to rise higher, extending through their whole thickness, and expanding the plate, in some cases, to double the amount supposed above. This condition greatly modifies the heat in bending the plates, which become more extended in length, and it adds considerably to the curvature of the boiler bottom. Accordingly, we constantly find, at particular times, a very serious deflection of boiler bottoms downwards at about the middle of their length. The depression commonly admits of accurate measurement, to the extent of a quarter of an inch or less, by placing a loose brick on the top of the bridge, just a little *out of contact* with the plates. And it regularly takes place in all boilers, to a greater or less extent, every morning *before the steam is up,* and before there is any pressure whatever, excepting what arises simply from the weight of water in the boiler.

Very little observation will convince any one that the peculiar action I have been describing really takes place. The fact is notorious that all boilers are more

or less leaky when the fire is first applied to them for getting up the steam; possibly the leak is so minute, in some cases, as to be scarcely discernible; but, generally, the leakage is sufficiently apparent when there is a clear fire under the boiler.

Now it is well known that, so soon as the water inside the boiler becomes heated, the leakage decreases, and, by the time it is boiling, and the steam begins to rise, every leak in the boiler bottom, except those that are running a full stream, is stopped, or nearly so. The cause is, clearly, that the heat, so soon as ebullition in the water commences, is carried off, by the formation of steam, from the inner surface of the plates, as rapidly as it is transmitted through them from the fire; and therefore, the temperature of the plates falls, or becomes uniform and, consequently, they again assume their original dimensions. The usual expression of the stoker then, is, that the *leaks* have "taken up," and by the time the steam is up, or sooner, the boiler is "as tight as a bottle." It is, however, the boiler bottom that is "*taken up*" by contraction and an equalization of temperature on each side of the plates. I am aware that this result is commonly ascribed to sediment being driven into the joints of the plates by the pressure; but the stoppage

of the leaks commences before the steam is up, and the same phenomenon occurs in boilers which are quite new, and which contain no sediment.

So far as a leakage of the kind just described may diminish the quantity of water in a boiler, it is obvious that it will be generally inconsiderable. A constant daily repetition of this process, however, causes much oxidation of the iron in the vicinity of the leaks, and induces weakness in some particular direction across the boiler bottom, which ultimately causes large openings between the plates, and, then, great loss of water results. And how the sudden loss of a large quantity of water in a morning, or at other times, before the steam is up, is likely to end in a violent explosion, at or about the time the engine starts work, will be sufficiently apparent from the explanations already given.

HOW CHANGE OF FORM PRODUCES FRACTURE.

It is evident that a greater amount of expansion and contraction will be produced at those joints of the plates which are immediately over the hottest parts of the fire than elsewhere. Suppose, for the present, that the whole of the plates in the boiler

bottom are heated uniformly; then, since the ends of the boiler are firmly braced to each other by means of the internal flue-tube, as well as by the upper half of the cylinder, neither of which are so much affected by the fire, it is clear that the expansion of one part of the boiler is resisted by the other part. The

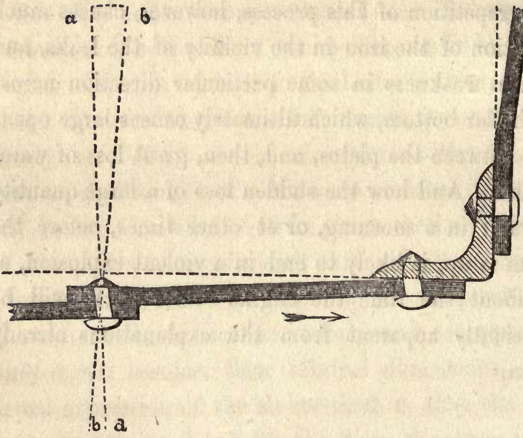


FIG. 7.

greatest strain from the expansion of the boiler bottom will be at the angles A and B (Fig. 6.) at which points, the rivets (if immoveably fast in the angle-iron) must have a tendency to bend outwards from the longitudinal thrust of the plate in that direction, as in Fig. 7, which is an enlarged representation of

the angle B in Fig. 6. The plate will also, sometimes, act as a lever in wrenching off the head of the rivet; or, as usually happens, by successive operations of this kind, the rivet-holes in the plates become permanently enlarged, and break out. For example, so soon as the water becomes sufficiently heated to cause ebullition to commence, however slightly, the temperature of the plates immediately falls to 212°, or to such a degree as corresponds with the boiling-point at the time. And this point being attained, of course, contraction of the bottom-plates immediately ensues, as before described, co-equal with the previous expansion. The thrust at the end rivets now becomes a drag in the contrary direction, or as shown by the position of the lines *aa* and *bb*, in Fig. 7, which represent the directions to which the varying position of the rivet respectively inclines, according as it is acted on by the expansion or the contraction of the boiler bottom.

If the rivets do not always give way, they enlarge the rivet-holes, which, by this alternating action, become oval or lengthened in the direction of the strain and, ultimately, cracks are formed between the rivet-holes and the edges of plates as shown in Fig. 8, which is a plan or top view of Fig. 7.

One object I have in view here is to show that severe strains upon the rivets of a boiler, arising from undue expansion and contraction, may be increased by the thickness of the plates, and that the destruction of boilers from that cause is not confined to those

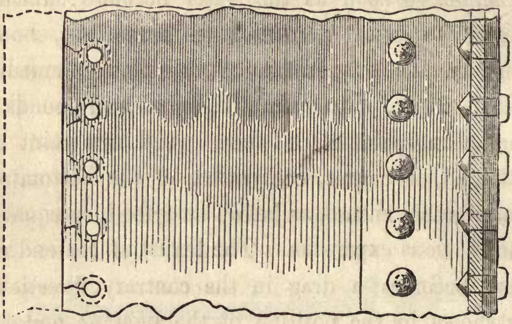


FIG. 8.

formed with angle irons and flat ends, but extends also to those made with hemispherical or "egg" ends, which are ordinarily considered superlatively safe high pressure boilers. Such boilers are usually of less diameter, and are consequently of greater length, on which account they are more particularly obnoxious to the defect I have been treating of, arising from a proportionately increased amount of expansion and contraction.

As a practical example, I shall conclude by describing a boiler of this kind which came under my observation a few years ago in London.

This boiler was 3½ feet diameter by 30 feet long, and set up with the ordinary wheel draught which is a very common, though a very improper mode of setting a boiler of so small a diameter. The consequence was that in order to obtain sufficient space for draught in the side flues, the brickwork had to be carried up considerably above the centre, and the boiler was finally covered over with brickwork; a dangerous practice though extremely common.

The reason for covering boilers in this way is of course to retain the heat, which it certainly does, but such a covering may be very detrimental to the durability of the boiler. Thus, when the fire is under the boiler, the temperature of the boiler bottom may not generally be more than about 250°, while that of the side flues cannot be less than 500 or 600 degrees, and the brickwork resting on the top of the boiler is seldom less than 350° or 400°, as I have frequently ascertained, and of course the iron in contact with it will be of the same temperature, except so far as the heat is carried off by the steam in contact with the metal. Now here may easily be a

difference of 200° or 300°, causing a considerable amount of expansion in the top of the boiler, and a corresponding strain upon the rivets in the boiler bottom. But supposing the boiler to be emptied by running out the water at the end of the week for the purpose of cooling and cleaning it out, or of cleaning the flues: and further, for the purpose of cooling it quicker, suppose that a quantity of *cold* water is immediately run into the boiler, and let us see the extent of the evil which takes place then. The hot brickwork will retain the upper half of the boiler, upon which it rests, at full stretch; while the lower half, at least so far as the cold water extends, suddenly contracts, and instead of 200° we may have a difference of 400° between the top and the bottom of the boiler, equivalent to about an inch in the whole length of the boiler.

As near as could be judged, on close examination, this was the precise extent to which several openings in the seam across the boiler bottom amounted to collectively. One or two of the dislocated parts becoming jammed, and retaining their positions permitted of exact measurement.

This gradual disintegration of a boiler has no doubt been frequently observed by others, although not

remarked upon. This particular example occurred at a factory where it was the custom to clean out one of the boilers every Sunday morning; for which purpose the stoker commonly filled the boiler he intended to clean immediately after letting out the hot water. And the case is adduced as an example of those cases where for years very great expenses were incurred in repairing and remaking the boilers without the cause of the defect having been discovered. Since, however, that practice of filling the hot boiler with cold water has been discontinued, although the boilers are now of thinner iron, larger diameter, and worked at higher pressure, a boiler-mender is scarcely ever required on the premises.

NOTE A.

(TO PAGE 137.)

EXPLOSION AT BROOKES'S FLAX MILL, BOLTON, JULY 1ST, 1844.

Although some of the conclusions arrived at in the American Report may admit of exception, evidences tending to corroborate the general accuracy of the committee's observations ought not to be withheld. So far as two or three instances of explosions go, I have had an opportunity of witnessing those appearances, which, to my mind at least, confirm the description given by the committee. As one example, I may refer to the explosion of a large boiler at the flax spinning mill, belonging to the late John Brookes, Esq., in Little Bolton, Lancashire, which I personally witnessed at the distance of about 300 yards from the mill, to which I was then on my way, when the accident took place.

First, a column of dust arose to a considerable elevation, in which some of the timbers of the roof of the building, which enclosed the boiler, were seen flying in different directions; then arose a cloud of

smoke, which spread out above in a large black canopy; through this a column of steam and water shot up to a very great height, which dispersed in moderately large drops, like a slight shower of rain in the direction of the wind, and to the distance of about 4 or 500 yards from the mill. At the same time, as a column of steam continued rising from another boiler in connection with, and nearly adjoining the one that burst, for about half a minute, and as the lower part of the cloud of smoke and dust began to clear away, flames commenced making their appearance, arising from a high building adjoining that which had been blown up along with the boiler; and which, in fact, as I afterwards found, had been set on fire by the burning coals from the furnace of the exploded boiler being driven in through the windows of the lower story of the building.

The boiler was of the waggon form, about 27 feet long by 9 feet wide, and 10 feet deep, weighing probably about 10 tons, and called 40 horse power. The lower portion, reaching up to the top of the side-flues, about three-fourths of the whole, was thrown in a single mass to about 20 yards from its seat; while the upper or semicircular portion, together with the steam-pipes, safety-valve, nozzles, and other

attachments, were thrown to a great height, and fell in the adjoining street, the ground of which was at an elevation of more than 20 feet above the level of the seat of the boiler.

The circumstance in which this Bolton Explosion differed from those in the American experiments, is remarkable, that is, in the report or sound produced. For if the report produced by the bursting of a very small boiler, only 10 *inches long by* 8 *inches in diameter,* was like that from the discharge of a cannon, what might we not expect from the explosion of a boiler 27 *feet* by 9, or about 5,000 times larger. But the fact is, that neither myself nor a friend, whom I was in conversation with at the time, heard any *report of that kind* at all, but only a rumbling sound such as might be supposed to arise from the cracking of the roof-timbers, the falling of the building, and the blowing-off of the steam from the other boiler, which had been working in connection with the one that exploded. There was a low continued rumbling noise, as described by some who were nearer to the scene of the explosion when it commenced, but it was certainly not *loud,* and, indeed, scarcely audible to us at the distance before mentioned, although our attention was particularly directed to the cloud of

dust and smoke which arose from the mill. It being not a little remarkable also that the subject of our conversation at the time was the deterioration to boilers from incrustation, and increased liability to accident from working higher pressure, which had then recently been adopted at this very mill, on account of attempting to work the engines more expansively on the Cornish system, but without the strong Cornish boilers. The destruction in this particular case, in my opinion, being greatly increased by using Mr. Williams's patent system of smoke-burning, which required the keeping of a *thick* fire (over 18 inches), and a stream of cold air passing up behind the fire-bridge. The area of the fire-grate of the exploded boiler was about 60 square feet, consequently it was charged at the time of the explosion with nearly 100 cubic feet of burning fuel. The effect of the sudden dispersion of such a mass of fire may be easily conceived. That portion of the boiler-bottom which extended over the fire-place, about 8 feet square, was torn right across, nearly in a straight line from side to side, exactly at the position of the bridge, besides being ripped up on one side through the seating-plates, and across the front end at the angle over the fire-door; thus this large portion, being liberated on three sides simultaneously, it was doubled

back on the other seating, as on a hinge or like the flap of a table, thereby opening out a hole of about 60 square feet in area, with an initial pressure of steam at about 20lb. per square inch. And immensely reinforced as that pressure would be by contact with the burning fuel in the furnace, it is not difficult to divine the great force of the explosion, and the consequent disastrous results that followed.

My first impression, on witnessing the commencement of the scene just described, was that it was the breaking out of a fire, and that, indeed, was the general impression of great numbers of the people in the streets of Bolton, who were making their way to the scene of the catastrophe, until met by the crowd of operatives, rushing out of the gates of the factory-yard, many of them cut and bleeding from the effects of the broken glass windows, which had been driven in upon the workers in several rooms of a six-story building, situated close to the boiler-house. It was through these windows that the burning coals from the large furnace were principally driven, which set on fire the machinery inside the mill, where the consternation and rush to escape was very great, as may easily be supposed, there being in the whole factory about 540 people employed at the time.

Respecting the peculiar sounds or reports produced by boiler explosions, it may be stated that the strangest discrepancies occur in the statements of professed eye and ear witnesses of this and similar explosions. For instance, in this case, more than one party testified to having heard the report more than two miles off, like that from the discharge of an immense piece of ordnance. All the London papers, true to their character of exaggerators of everything, had it, that the people of Bolton were suddenly startled as with a loud clap of thunder; and some of them stated that the *whole town was alarmed as with an earthquake*, an opinion which the country papers also shared, *after* the London newspaper reports reached them.

R. A.

NOTE B.

(TO PAGE 145.)

THE "SPHEROIDAL CONDITION" OF WATER.

The term *"spheroidal"* was, I believe, first applied some years ago to that particular condition water is in when repelled from a hot surface in the form of roundish drops, by Mr. J. E. Bowman, then Professor of chemistry at the Royal Institution, Manchester, and since of King's College, London. This was on the occasion of his reading a lecture on the subject of steam boiler explosions, in the above institution, in the course of which he was the first, perhaps, in this country, to give an account of, as well as to show experimentally some of those remarkable properties of water and other liquids when projected into red hot vessels, since made popular by some curious performances at the meetings of the British Association, and more recently at the British Institution, by M. Boutigny, of Evreux, in France.

This gentleman, who had been some years engaged in the prosecution of researches connected with the

subject, was, until the delivery of Mr. Bowman's lecture, above referred to,* and its subsequent publication, generally supposed to be the first who had attempted to "account for explosions on the supposition that water in them passes, under certain circumstances, into the spheroidal state." Sufficient evidence, however, was furnished to Mr. Bowman on that occasion, that I had been many years well acquainted with the principle of the spheroidal condition of water in boilers, its tendency to create priming and to promote explosions, although I had never thought of giving it that or any other distinctive appellation. That I had several years prior to its, no doubt independent, discovery by M. Boutigny, also applied it to account for some of the explosions of steam boilers, was a fact which Mr. Bowman very handsomely acknowledged both in his lecture, which was followed by a public discussion on the subject, and also in his pamphlet, by quoting at length passages containing evidences thereof from a pamphlet of mine, published in 1836-7. An instance of libe-

* "On some remarkable properties of water and other fluids, with reference especially to the causes and prevention of steam boiler explosions." By John Eddowes Bowman. London: J. W. Parker, 1845.

rality and justice so honourable, though rare, among scientific writers, that I cannot omit this opportunity of publicly acknowledging it. And I may here notice the fact that, although partly printed in 1836, my book was written and the manuscript perused by several friends nearly three years before that time. The complete application of the discovery to the theory of explosions was in reality made by me previous to 1830, when, in conjunction with my then partner, Mr. Henry Wright, engineer of Manchester, I made application for a patent, embodying the principle of the repulsion of water from over-heated boiler bottoms and front tube-plates of locomotives, being one cause of the priming of steam boilers, as well as causing explosions. During the years 1831 and 1832, it is quite notorious, in Manchester, that I frequently exhibited the principal experiments relative to it, in explanation of the bursting of boilers. Small *glass* boilers were purposely exploded with that view in the presence of well known parties in numerous instances.

The simplest mode in which those unused to experimenting may most conveniently at any time readily demonstrate the "spheroidal condition of water," is that of heating the bowl of a large tea-

spoon over the flame of a candle until water runs off without *wetting* it. Then, by the aid of a dropping tube, or a quill, or any other means of measuring into the spoon successive drops of water of the same size, the leading facts of the repulsion of liquid in the form of beads or spheroids become very apparent. Thus a moderately small-sized bead or globule of water, when the spoon is very hot, will be observed to rotate rapidly on its axis, all the while moving quickly about, supported by a thin film of steam, and occupying half a minute or more perhaps before it is entirely evaporated. If now, without reheating the spoon, and *while, in fact, it is rapidly cooling,* we place another drop of water of exactly the same size in the same position as the first, it will, after assuming the same spheroidal appearance, rapidly diminish in size, and evaporate entirely away in two or three, or, at most, in a very few seconds. A third drop so placed will be found generally to disappear in less than one second; or, if the experiment be carefully managed, the last drop will be made to vanish instantaneously and without assuming the globular or spheroidal form. The temperature of the metal of which the spoon consists will then of course be that of maximum

vaporisation, and which is usually found to be considerably under 400° Fah. By the American experiments it was found to be about 350°, and the temperature of perfect repulsion of drops of water, projected into an iron bowl a quarter of an inch thick was 405°. The committee also refer to a series of experiments by Professor Johnson, who places the maximum evaporating point at between 304° and 320°, and in their general view of the facts detailed, state that the repulsion between the metal and the water is perfect at from 20° to 40° above the point of maximum vaporisation, at which temperatures the water does not wet the metal.

Some of the conclusions arrived at by the committee are as follow:—

1. The temperature of maximum vaporisation, both in copper and iron, is lower as the surface of the metal is smoother, and the amount of vaporisation in a given time is much diminished.

2. The temperatures of maximum vaporisation, for copper and iron in similar states of surface, differ between 30° and 40°, the iron having the higher point.

3. The time of vaporisation, at the maximum, is less in the copper than in the iron, in the ratio of

about 2 to 1, probably, nearly in the ratio of the conducting powers of the two metals for heat, which are as $2\frac{1}{2}$ to 1. (See American Report, Page 47.)

It must be observed that the above results are from drops, or small quantities, of water, under atmospheric pressure only. And, however interesting they may be in a philosophical point of view, they cannot be said to touch the practical question of the effect of large quantities of water brought suddenly into contact with hot metal, in producing explosions.

Accordingly, some experiments with cast iron bowls, half an inch thick, containing large quantities of water, placed over charcoal fires, indicated that the highest point of greatest evaporation was placed, at least, about 200° below red heat in daylight, and in the most favourable circumstances, varying from 550° to 600° Fah. for wrought iron, and from 470° to 526° for copper.

In the course of the experiments of the American Committee, it was observed that, with other liquids, Alcohol for instance, at a certain temperature of the dish, that of the spheroid became stationary at $169\frac{1}{2}$° or 170°, (the boiling-point being 173°) and that it could not be raised higher; indeed *the temperature of the spheroid became lower* as that of the dish was

higher. In my own experiments, that point not appearing to me then to have any direct useful application, I had only generally remarked that the temperature of the globule of water must be lower than 212° from the fact that it did not boil. And it is entirely to the delicately manipulated experiments of Messrs. Bowman and Boutigny that we are indebted for a knowledge of the fact, that the temperature of a spheroid of water is invariably constant at 205°, or 7° below its boiling-point, however hot the crucible which contains it may be. Thus, also, a spheroid of *alcohol* always stands at 170° or 3° below its boiling-point; one of *ether* is always 5° below, or 95°; and liquid *sulphurous acid* which boils at 14°, never reaches so high even as that low temperature when in the spheroidal state, but continues far colder than melting ice, even though the crucible in which it lies be all the time *at the most intense white heat.* It was on this principle that M. Boutigny contrived the feat of freezing water in red hot crucibles, and afterwards that of handling melted cast iron.

R. A.

APPENDIX, No. I.

REMARKS ON SMOKE-BURNING BY JOHN BOURNE, ESQ.

[The following remarks form a portion of a review of Mr. Charles Wye Williams's book on "The Combustion of Coal and the Prevention of Smoke chemically and practically considered," which appeared in the "Artizan" for February, 1843.]

The smoke evolved by every species of bituminous coal, when burned in common furnaces, must necessarily detract considerably from the calorific efficacy of the fire, both on account of the direct loss of a portion of the combustible which passes off in the form of smoke, and is dissipated in the atmosphere, as well as from the loss of the heat requisite to convert the hydrocarbons, so dissipated, into the gaseous form. Numerous attempts have been made to obviate or diminish these sources of waste, by admitting into the flue or furnace a stream of air,

to accomplish the combustion of the inflammable parts of the smoke; but the difficulty of apportioning the quantity of air admitted, to the varying wants of the fire, has been found an insuperable objection in the case of ordinary furnaces; whilst the refrigeratory effect of the excess of air it is necessary to admit, in order to bring the atoms of the combustible and the supporter within the range of combining attraction, goes far to neutralize the increased heating power consequent on their combination. In experiments upon smoke-burning furnaces, conducted with great care and skill, possibly some little saving may have been repeatedly realized; but with the measure of care and skill which furnaces can obtain in the ordinary routine of practical operation, smoke-burning has invariably been productive of a diminished efficiency or an increased consumption.

All this Mr. Williams acknowledges; but maintains that his is not a smoke-burning, but a smoke-preventing furnace. Smoke, he admits, cannot be burned advantageously; but it is not smoke, he says, but gas, that he attempts to consume. The difference is certainly conceivable, and not unimportant; yet, on looking at the construction of Mr. Williams's furnace, we find that the furnace proper differs in no respect

from common furnaces; and the aeriform matter which passes through the furnace-throat must, therefore, necessarily be of the usual description. The whole of Mr. Williams's plan, indeed, consists in letting air into the flue by a multitude of holes; but the substance to which the air is admitted is identical with that in furnaces of the ordinary kind; and his furnace is, therefore, just as much a smoke-generating furnace as any furnace whatever. The difference between smoke and gas is simply this: one is the product of imperfect or incomplete combustion, whilst the other is not the product of combustion at all, but of volatilization merely; and, as combustion is carried on in this gentleman's furnace, the substances flowing past the diffusion-orifices, which are the product of that combustion, cannot be coal-gas by any possibility. The question really at issue is not whether it is beneficial to admit air to gas in one hole or in many holes, but whether, in the case of this furnace, it is gas at all to which the air is admitted. To pretend that smoke can be turned into gas, by letting in air upon it by one hundred holes instead of by one or two, is just as preposterous as to maintain that the plant which, when watered with a common watering-pot, is a lily, will be turned into a thistle if watered

with a jug. In spite, then, of all the indignation Mr. Williams has heaped upon "smoke-burning pretenders," it is, in our eyes, undeniable that he is himself one of the genus he so loudly condemns; and as we participate to a certain extent in his disapproval of smoke-burning expedients, we are compelled to surrender him to his own reprobation.

The ineffectual and injurious character of Mr. Williams's arrangements are, we think, very ably pointed out in a report of Mr. Armstrong's addressed to a respectable manufacturing firm in Manchester, and inserted at p. 102 of the present work.

In answer to this statement, Mr. Williams contends that when there is no smoke to be burned, there is carbonic oxide, and that therefore a rush of cold air through the diffusion orifices, at any time is impossible. But if the furnace be made to produce carbonic oxide in considerable quantity at all so as to combine with the oxygen when there is no smoke, this carbonic oxide must pass off unconsumed where there is smoke, provided the smoke be consumed, and a great waste of fuel must thereby be occasioned. In the case of ordinary furnaces, it appears impossible indeed for Mr. Williams to extricate himself from this dilemma; he must either have a current of cold air rushing at times through the

diffusion orifices, cooling and injuring the boiler, or large quantities of carbonic oxide continually escaping into the chimney, so as to occasion a material waste of fuel. On the whole, it appears to us that although this project may be capable of affording some satisfaction so long as it meets with the care due to a novel and nurseling project—as, indeed, a host of previous schemes have repeatedly done—yet that in the aggregate of ordinary working, it will approve itself troublesome, expensive, and pernicious.

Of Mr. Williams's book, our verdict, we fear, must be as unfavourable as of his invention; yet it has received high praise in various quarters; and although its admirers are not the best sort of admirers, we doubt not their panegyric has been accepted by Mr. Williams as good sterling praise, and will probably render distasteful any more discriminating analysis. Indeed, the expectations of any author who has once tasted of popular applause, are by no means easily satisfied. Upon his first appearance before the tribunal of public opinion, he will generally be content if he escape without censure; but his expectations rise with his success, and the judgment he would at first have accepted with joy and gratitude, he will speedily come to look upon as prejudiced and disparaging. Upon any person, indeed, prominently before the public, a

word of disapprobation falls with prodigiously increased weight: so long as he remains in obscurity, reproof is unattended with disgrace because it is necessarily unwitnessed, but the crowd he brings around him by his triumph, if it adds to the brilliancy of success, fearfully aggravates the penalties of failure. Every voice which swelled the measure of his fame will add to the ignominy of his degradation; and a measure of praise which would have exceeded the hopes of his earlier ambition will now only suggest humiliating ideas of his unfitness for the position he has so incautiously usurped, and the derision and disappointment his incapacity has excited.

An inquiry into the phenomena attendant upon the combustion of coal divides itself into two parts. First, The determination of the chemical constitution of the coal; and, Second, The determination of the quantity of air requisite for the combustion of its constituents. Mr. Williams has gone into both of these subjects at considerable length. He has given us a compilation of authorities showing what the chemical composition of different species of coal is, and has favoured us with several chapters and a multitude of diagrams to point out that carbon and hydrogen combine with oxygen in definite proportions.

In the whole of these most ingeniously constructed chapters, there is not a single remark of the least worth or moment; and in the whole length and breadth of the book there is nothing new, except its errors and the magisterial solemnity with which the most trite and insignificant truths are reproduced and paraded. Indeed, Mr. Williams seems very fond of burning his gas in the blaze of noon-day. He devotes pages to prove self-evident propositions, and takes infinite pains to convince sceptics of things nobody ever thinks of doubting. He continually speaks of atoms as if he himself had found them out, and as if an introduction to so difficult a theme inspired extraordinary trepidation; as in page 40, for example where he encouragingly tells us *"not to feel alarmed* at this introduction to elementary atoms and chemical equivalents." In pages 27, *et seq.*, the discovery is announced to us, that when fresh coal is thrown upon a fire, the fire is afterwards not quite so hot as before; in pages 28 and 29, we are assured that heat is necessary to expel gas from coals; in page 35, that a combustible as well as a supporter are indispensable to combustion; and in page 37, that the combustion of gas is accomplished, "not by its combination with the air, as is the vulgar and dangerous notion, but with

the oxygen of the air—the supporter of flame—the heat-giving constituent of the air." In page 91, we are told, "Without sufficient time, nothing short of a miracle could satisfy the required extent of diffusion. Nature, however, does not operate by miracles, but by defined laws and progressive means;" and in page 129, we are assured that combustion cannot take place without air; "that providing heat is not providing air, neither is decomposition combustion." In page 11, we are told that Sir Humphrey Davy was an eminent man; in page 20, that Dr. Faraday is the first electrician of the day; and in page 41, that John Dalton is a writer of merit. At page 70 commences a chapter of 30 pages for the purpose of pointing out that as it is oxygen which supports the combustion is a furnace, the air supplied to the furnace must not have been deprived of its oxygen previously, else it will not do:—for thus wisely and thus learnedly argues this philosopher, "If oxygen be not present in the air, how can it otherwise be obtained? How can we effect a union with a thing which is not?"

In extenuation of the marvellous superficiality of this gentleman's treatise, it may, perhaps, be urged that he wrote not for scientific, but for practical men. This argument might, perhaps, have some weight if

by practical men were meant our working boiler smiths and bricklayers, who for the most part are supposed to know as much of chemistry as of the Œlic reduplication; yet, even in this case, we do not altogether see how those persons should be induced to read this book more readily than some of the numerous chemical works to which they already have access. Mr. Williams, however, informs us that he does not address himself to so unpromising an auditory, but to those by whom engineering works are directed and designed. 'Are then our bricklayers or boiler-makers to become chemists? No. But those who direct—those who assume the charge of teaching them to construct the numerous descriptions of furnaces with which this country abounds, should be masters of the leading principles on which their art is based, and the success of their operation depends,' of which it would appear they at present know nothing. Thus in page 2, Mr. Williams informs us, that, even the most experienced engineers know very little about the boiler—in page 3, that in the construction of boilers engineers are without any fixed principles to guide them—in page 4, that he has watched the efforts of engineers to arrive at some degree of certainty, and that he has perceived the absence of any intelligible or well-founded prin-

ciple in the boiler—in page 5, that instead of improvement there has been latterly retrogression, and that well-established houses even yet know very little of the principles of perfect combustion, or of the economy of fuel. From these and numerous other passages, which might be cited, it would appear to be this gentleman's doctrine that engineers are a very ignorant and stupid race of persons; that though living in England in the nineteenth century they are unacquainted with the simplest and most familiar truths of chemistry; and while possessing the reputation of producing those miracles of ingenuity which carry their fame to the verge of civilization, that they exist in a state of mental stupor which the most besotted Turk could scarcely hope to emulate. A person, indeed, who derived his only information on this subject from Mr. Charles Wye Williams, might imagine our mechanists to be the descendants of some barbarian horde on whom a hereditary curse rested, dooming them to an eternal degradation; who remained rude and untutored even in the centre of civilization, and whom the flame of science could neither melt nor quicken, nor the lessons of experience instruct. It is not astonishing, therefore, that Mr. Williams should speak with much confidence and coolness of the ab-

surdities of the practice of our engineers, which in pages 34, 72, 73, 74, 127, and, indeed, in almost every page throughout the volume, he most industriously exposes. He takes especial care to make manifest the shallowness of Tredgold, and the erroneous notions of Watt, which he of course contrasts with his own higher skill and superior illumination, and finding himself unable to refute what they *do* say, wisely confines his refutation to what they *do not* say. In page 134, he states, 'the erroneous view of the combustion of the gases began with Watt;' but after handling poor Watt very severely for his manifold shortcomings, he kindly winds up in the following patronizing strain:—'But let justice, however, be done to Watt. It is not his fault that the errors he committed should continue to be repeated,' which our present engineers are, it appears, wrong-headed enough to do. The following epithets are therefore unsparingly applied to the practice of those obdurate persons; 'erroneous,' 'lamentably erroneous,' 'neglect of chemistry,' 'notable instance of neglect of chemistry,' 'abortive attempts,' 'great practical and chemical error,' 'palpable oversights,' 'unsound principles,' 'chemical blunder,' 'utterly at variance with chemical propriety,' and a host of other equally decorous and appropriate

expressions. The secret of all this we suppose is, that Mr. Williams plumes himself not a little upon the smattering of chemistry he appears to have acquired, and in the simplicity of his heart imagines that because our leading engineers do not think it consistent with their dignity to become lecturing itinerants, or to be eternally flashing their attainments in the eyes of ignorant spectators, they know nothing of the most familiar scientific truths, and pay no regard to them in their practice. If Mr. Williams could only see himself as he is seen by others—if he could only perceive the ridicule he draws upon himself, by harping everlastingly about chemical principles, and chemical blunders—and which we can assure him raises the secret laughter of even the most favourably affected—he would, we are sure, gladly retire into the obscurity for which Providence manifestly designed him, and leave the contention for distinction to those who have something better to offer as credential than a flood of scientific jargon, or the pitiful pedantry of a boiling empiric.

J. B.

APPENDIX, No. II.

AMERICAN EXPERIMENTS ON EXPLOSIONS,

Made by order of the Treasury Department of the United States, in which, among other instructions on the subject, directions were given.

"*To observe accurately the sort of bursting produced by a gradual increase of pressure within Cylinders of Iron and Copper.*

"It has been contended by some, that ruptures produced by a gradual increase of pressure within steam boilers do not bear the character of explosions, but that a mere rending takes place, giving escape to the contents. This has been assumed to be especially the case with copper boilers. To make the observation required by the above question, cylinders of iron and copper were prepared, of sufficient size, to make a small thickness of material answer for rending by a pressure which was easily attainable. Two experiments made, one with an iron and another with a copper cylinder, afforded so direct an answer to the query that it was not deemed necessary to carry the experiments further, especially as they were tedious, and not without danger. A further experiment of the

same tenor, resulted from a trial of Perkins's assertion in regard to the effect of making an opening in a vessel containing water, and heated to a high temperature.

"The boilers used were cylindrical, eight and a half inches in diameter, and ten and twelve inches respectively in length, of iron ·02 inch thick, and of copper ·03 inch thick, having iron heads ·05 inch thick, to which the convex surface was fixed by iron rivets, placed nearly touching each other. A single opening in the middle of one of the heads of each boiler was provided to introduce the water, and was furnished with a screw, into which to insert a tube and piston, connected with a small spring weighing machine, which is represented at *a* in the cut on page 124. Upon the cylinder of this machine a ring was placed, which was moveable along the cylinder by a slight pressure: this ring was forced towards the end of the cylinder nearest to the boiler head, as the spring was bent, and remaining in its place when the spring relaxed, served to register the maximum pressure to which the piston had been exposed previous to observing it.

"The iron boiler was placed in a heavy cylinder of wrought iron, which served as a furnace, the axis of the boiler being nearly horizontal, and that of the furnace cylinder vertical. The boiler, having been

half filled with water, was placed upon a fire of charcoal, and when the water boiled, the register machine for the pressure was screwed in.

"The place selected for the experiments was in a deserted quarry on the banks of the Pennypack, near Holmesburgh. The high bank served as a protection, by the aid of which the experiments were viewed with little danger. A wire and cord were attached to the head of the boiler, to draw it from the fire when the latter required to be replenished. A leak in the riveting of the iron boiler allowed so much steam to escape that the boiler did not give way on the first trial. As soon as the escape of steam was observed to cease, the boiler was removed from the fire and again half filled with water. The fire was urged, and the boiler settled lower into it, and by once replenishing the fuel, without removing the boiler, an explosion was produced. Part of the committee were engaged in observing the progress of the experiment at this moment. The fire was near the middle line of the boiler, burning not strongly near that line, but very rapidly below the boiler; the steam issued freely through the leak before alluded to, and the whistling sound which it produced, and which had increased gradually in strength as the experiment progressed,

seemed constant. The length of time during which the steam had escaped showed the water to be low, and induced the supposition that a second time the object would fail; when an explosion occurred. The explosion tore off one of the heads, *b c*, of the cylinder, projecting the other parts of the boiler in an opposite direction, carrying with them for a portion of the distance, the iron cylinder forming the furnace, and scattering the fuel in every direction. The report attending the explosion resembled that from a small mortar (eprouvette) fully charged, the steam mixed with the smoke was not considerable in quantity, and few marks of water were to be seen. The boiler head was thrown fifteen feet, the boiler and spring register about six feet, and the furnace, weighing about forty-five pounds, was overturned and carried four feet. The pressure indicated by the register was eleven and a quarter atmospheres.

"In examining the boiler it appeared that the head, *b*, which was thrown off, had first struck against the iron furnace, which had deflected it outwards; this is shown by the indentation, *b c*, in the figure. This head was forced off all around in the line of rivets which attached the head to the boiler, the metal remaining between the rivets being less than the space

occupied by them. The convex surface and the other head were thrown likewise against the furnace, and the head indented at *d e*, overturning the furnace and carrying it four feet, as already stated. The boiler finally struck against the side of the bank of earth. The piston of the weighing machine was somewhat bent in the experiment.

"The circumstances of this experiment show that the steam rose quite gradually on account of leaks in the boiler, increasing, probably, *more rapidly as the quantity of water diminished*, the intensity of the fire meanwhile increasing. That at a certain period the tension within had attained about eleven atmospheres, when the boiler *exploded violently*.

"The accompanying figure (3) will serve to give an accurate idea of the appearance of this boiler after its rupture.

"The cylinder of copper, before referred to, was next put in the place of the iron boiler, and the fire again kindled; the general arrangements being as before described. This boiler being longer than the former would not descend so far into the furnace, and an attempt to raise the steam sufficiently high to burst it failed: there was a considerable leak in the junction of the curved surface with one of the ends. When

the water was nearly exhausted, the fire having passed its period of greatest heat, the cylinder was removed and water again introduced, filling about three-fourths of its capacity. A new furnace was constructed of stones, allowing the boiler to rest more closely upon the fuel, and affording a screen from the wind which was blowing quite strongly. The part of the boiler in which the leak had been observed was turned downwards, but a similar escape was found for the steam in the part now uppermost. The tension of the steam appeared to increase very slowly, and the fire passed its best action without effect; it was renewed, and as the water became lower the tension of the steam increased considerably. As before, nothing remarkable occurred previous to the instant of explosion, and the members of the committee, employed in the experiments, were engaged in observing the boiler at the instant it exploded. A dense cloud of smoke and flame, capped by steam, rose from the pit; the stones and combustibles were widely scattered, and the boiler was thrown, in a single mass, about fifteen feet from the furnace. The noise attending this explosion was like that from the firing of an eight-inch mortar.

"The boiler was rent as shown in the accompanying figure (4), giving way in an irregular line just above the

probable water line on one side of the boiler, but not conforming to it. *d* and *b* were the lowest points in the two heads before the explosion. The sheet of copper was torn from the heads, unrolled and irregularly bent, adhering to the heads for only a short distance near the top of each; and the heads were bent outwards. The thickness of the copper along the line of rupture varies from ·025 to ·035 of an inch, and the metal appears to have been highly heated at one end of the torn portion. The piston of the spring gauge was bent, the screw which attached it to the boiler broken, and the whole instrument otherwise injured; it appeared that the wire intended to draw the boiler off the furnace had slipped and impeded the action of the piston, so that no register of the amount of force producing this explosion was obtained.*

"The circumstances, as before, show that the steam was allowed to rise gradually until the boiler gave way. It is possible that there may be a relation between the space occupied by the water and that in

* "Assuming the strength of copper at 36,000 lbs. to the square inch, and that it was uninjured by the heating, neglecting also the effect of temperature, the bursting pressure appears by calculation, to have been about sixteen atmospheres. It was, no doubt, less than this."

which the steam is formed most favourable to the production of steam, and that when this was attained a rapid rise in elasticity took place; but there were no circumstances observed which would confirm such a view, and if it were correct it would only affect the conclusion as far as the increase of tension might have been rapid from such a cause.

"As in the former case the marks of the sediments remained in the boiler, and indicated that the water was about an inch deep when the cylinder exploded. Much more steam was formed, and more water left than in the first experiment.

"These experiments, together with the one referred to in a subsequent part of this report, *are direct and conclusive;* they show that *all the circumstances attending the most violent explosions may occur without a sudden increase of pressure within a boiler.* There can be no doubt, however, that if particular portions of a boiler are much weaker than other parts, they may give way in time to prevent such a catastrophe."

(From "REPORT of the Committee of the Franklin Institute of the State of Pennsylvania for the promotion of the Mechanic Arts, on the EXPLOSIONS OF STEAM BOILERS. Part I.—Containing the first report of experiments made by the Committee for the Treasury Department of the United States." *Philadelphia*, 1836.)

CONCLUDING NOTICE.

I have been constrained, only by considerations of space, to omit descriptions of several excellent boilers both of the multitubular and flue construction. Among the former are those of ANDREW (locomotive), BARRANS (cup surface), BURNEY (river boat), GORDON of Stockport, and HOLCROFT of Manchester. And among the latter are CAMERON'S (upright conical furnace), COWBURN'S (cellular), and DUNN'S (patent vertical), all of which are among the best of their respective kinds.

ERRATA.

Page	Line	
44—	9 from bottom	for "as," read *of*.
110—	6 "	" conducted," read *witnessed*.
124—	1 "	after "page 66," add *p.* 187 *of this book*.
133—	10 "	for "Fig. 4," read *Fig*. 3.

PRINTED BY G. WATSON, 5, KIRBY STREET, HATTON GARDEN.